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Building Integrated Technical Food Systems

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// BUILDING INTEGRATED TECHNICAL FOOD SYSTEMS //

VOLUME 1 of 2

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//THESIS ABSTRACT//

For millennia, food has been grown within, or immediately adjacent to cities. However, as cities increased in size, they quickly outgrew their native hinterlands and began to import food from elsewhere to sustain their ever-growing urban populations. Today, the importation of food from around the globe is commonplace, and it is estimated that a quarter of all food grown for human consumption is traded each year globally (D'Odorico, et al., 2014). As a result of this, food production has been pushed further and further away from urban centres. Sometimes, however, it is necessary to bring back this ancient practice when the reliance on imported food is no longer an option. During the second world war, the UK government created the 'Dig for Victory' campaign; encouraging citizens to plant crops in their gardens and local parks to subsidise the provision of food that would have otherwise been imported from Europe or the USA. More recently, in Cuba, the growing of food within cities has become a proven practice once again as a method to secure sustenance for urban populations in response to complications relating to the importation of food.

By 2050, it is anticipated that food production will need to increase by 70 percent in developed countries and 100 percent in developing countries, when referring to production values of 2005 through to 2007 (Bruinsma, 2009). However, in countries such as the UK, where there is little to no available land for additional food production, and only marginal gains available as a result of improved methods of agricultural intensification, it is the city that is considered by many to be the future context of increased food production. In high-density cities such as London, Manchester and Birmingham, available space is in short supply at ground-level, which has been an essential commodity for successful transitions to urban agriculture in recent history. As a result, the focus turns towards the surface area of the buildings that form today's cities, and the internal floors that lay within them, as the future locations of increased food production through the use of 'technical food systems'. Technical food systems utilise man-made components such as plastic trays and mechanical pumps to grow crops directly in water, without the use of soil, and promise increased productivity, as well as decreased water and energy use

when compared with traditional agricultural systems. Some see urban agriculture as the solution to increasing both domestic and global food production to mitigate such problems as hunger, ecological damage and global food transport. However, to others, it is seen as a design trend that offers no realistic alternative to the global food system as it exists today. Thus, there are conflicting opinions as to the impact urban agriculture could have on domestic food production, global food security and the mitigation of ecological damage.

At first glance urban agriculture offers some obvious benefits over traditional agricultural practices such as the growing of food in areas that are already developed, which reduces the need to cultivate land elsewhere, and the growing of food where demand is highest, which can lead to reductions in food transport, packaging and storage - i.e. chilling and freezing. However, in the developed world the practice of urban agriculture is advertised, so to speak, as a succession of purpose-built edifices filled with lettuces or livestock. In many ways, this weakens the argument for agricultural cities as an alternative to current food production methods because it illustrates a practice that is dependent on substantial investment and the demolition of existing buildings to succeed. Within this thesis, these large utopian agricultural skyscrapers are pushed to one side, and existing buildings within existing cities become the focus. The generalised question of 'how much food can urban agriculture produce?' is repurposed and more accurately posed as 'how much food can urban agriculture produce within or upon existing buildings as part of today's cities?'.

The delivery of the thesis is not dependent on a pre-existing hypothesis that urban agriculture does or does not impact domestic food production. Instead, it relies on the design of real-world experiments, the development of simulated analysis and the construction of logical arguments to determine the differing impacts of urban agriculture in the most objective way possible. Although the thesis focuses on the contribution UK cities can make to food production, it does so by firstly understanding the challenges that face the integration of urban agriculture. Only by achieving this understanding can the productive capacity of all UK cities be more accurately calculated, and the possible benefits of urban agriculture such as job creation and improvement in urban wellbeing be quantified and qualified. Ultimately, the thesis focuses on a lineage of inquiry that aims to quantify the impacts of urban

agriculture through the construction of a working building-integrated aquaponic system, the light capture analysis of urban centres and the calculation and postulation of possible additional benefits to urban populations.

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Together, we co-designed the elevated aquaponic system contained within this thesis, and I simply do not know how I would have completed this if it wasn't for her. I would also like to thank my beautiful and crazy daughter Orla for bringing joy into my life when times were hard, and for always reminding me that there is a more important world beyond the computer screen. I would also like to thank my parents - Karen, Ian, Renita, Carol and Stan - for their love and support, as well as their hard work and dedication, which has enabled me to chase my dreams. Finally, I would like to extend a huge thank you to Professor Greg Keeffe who was the instigator of this research and the driving force behind the delivery of the elevated aquaponic system. He has been a constant source of inspiration throughout this process, and without him, none of this would have been possible.

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//LIST OF ACRONYMS//

ATSDR	Agency for Toxic Substance and Disease Registry
BDP	Building Design Partnership
CO ₂ e	Carbon Dioxide Equivalent
COPD	Chronic Obstructive Pulmonary Disease
C4SLS	Category For Screening Levels
ESA	United Nations Department of Economic and Social Affairs
FAO	Food and Agriculture Organisation of the United Nations
GMO	Genetically Modified Organism
HMRC	Her Majesty's Revenue and Customs
ICSER	Interdepartmental Committee on Social and Economic Research
IPCC	Intergovernmental Panel on Climate Change
IWM (EB)	Chartered Institution of Waste Management (Environmental Body)
LiDAR	Light Detection and Ranging
MIF	Manchester International Festival
NCDs	Noncommunicable Diseases
NHS	National Health Service (UK)
ONS	Office for National Statistics
PAR	Photosynthetic Active Radiation value
PPM	Parts Per Million
QUB	Queen's University Belfast
RIBA	Royal Institute of British Architects
UK	United Kingdom
WTO	World Trade Organisation
WWF	World Wide Fund for Nature

1.0

INTRODUCTION

1.0 // INTRODUCTION //

Within this initial chapter, a brief introduction is given to the issues that directly inform the aims and objectives of the thesis. These aims and objectives are then consolidated into succinct research questions that drive the thesis throughout. The need for the research is also identified along with a brief introduction to the methods that will be utilised to answer each research question. An overview of the thesis is also been provided.

1.1 - Ecosystem services and cities

In 2011 the world's population rose above seven billion people for the first time in human history (United Nations Population Fund, 2011); having increased by one billion people approximately every twelve years since 1975. At a similar point in history, the world's population had also become predominantly urban for the first time. This transition occurred during 2009 when the world's urbanised population reached 50.1 percent (ESA, 2009). The populations of developed countries, however, have been predominantly urban for much longer, with one of the very first urbanised populations recorded as 50.4 percent in the 1851 British census (ICSER, 1951). In 2009, the percentage of people in developed countries living in cities had risen to 74.9 percent (ESA, 2009), which is expected to rise to 87 percent by 2050 (ESA, 2012). The phenomenon of urban migration in developing countries poses more pressing issues than those associated with urban migration in developed countries such as overcrowding, access to water and poor sanitation. It is estimated that developing countries will have a combined total of 5.1 billion urban inhabitants by 2050, compared with 1.1 billion urban inhabitants in developed countries (ESA, 2012). With over 3.5 billion people living in cities today, and an estimated 6.25 billion people living in cities by 2050, the way in which urban centres are supplied with food, as well as fresh water, clean air, and other natural commodities - otherwise known as 'ecosystem services' - needs to be better understood and addressed.

Ecosystem services are primarily described as the benefits that people obtain from ecosystems (Millennium Ecosystem Assessment, 2005). These include, but are not limited to, food, natural fibres, purification of water, air filtration, regulation of pests and diseases, pollination, habitat for wildlife and beneficial species, microclimate regulation, medicinal substances, noise reduction, carbon sequestration, nutrient cycling, open space, cultural heritage, and protection from natural hazards such as floods. Throughout human evolution, mankind has depended on the provision of ecosystem services, and since the creation of the first permanent settlements, this dependence has not changed. In fact, it is only through the access to, or production of, a surplus in ecosystem services that the first permanent settlements were able to manifest.

The near eastern centre of agricultural development - also known as the 'fertile crescent' - is one of the more well-known centres of early agricultural practices. It is known as the fertile crescent due to its shape and the rich lands that were left behind as the last ice age thawed and retreated north. This area of fertility ran from the Nile delta, along the eastern coast of the Mediterranean up to the south of Anatolia (modern-day Turkey), before returning south along the River Euphrates through Mesopotamia (modern day Iraq) to the Persian Gulf. Due to its fertility, this region became home to vast oak forests and lush grasslands that were grazed by the ancestors of modern sheep and goats. As many animals tracked the retreat of the ice, it is believed that the caloric pressures on human populations grew to a point where mankind had to move from the predation of a meat-based diet to the exploitation of a grain-based diet to survive (Steel, 2013).

The protein requirements of these early farmers still came from hunting, fishing and gathering legumes, but the largest portion of their diets now relied on the exploitation of abundant plant life. To secure enough food for their families, pioneer harvesters were believed to have set up temporary camps to collect ears of grain at the exact time of ripening. This practice, over millennia, led to the development of the first permanent settlements, such as those found in Palestine from around 10,000 BC, consisting of groups of low circular stone-walled huts with timber superstructures (Mazoyer, et al., 2006). The intensive gathering of wild grains would have been extremely labour intensive but this hard work - consisting of winnowing, threshing and grinding - would ensure that sufficient quantities of food could be gathered and

stored for some people, at least, to remain stationary. The harvesting and storing of grain was, therefore, a technique that very nearly ensured food surplus, which over millennia became more secure as methods were refined, and the saving and scattering of seed became commonplace (Steel, 2013). This slow transition from predation to agriculture took well over 1,000 years, and it revolutionised the technological, economic and cultural aspects of human life (Cauvin, 2000). This symbiosis between nature and settlement, albeit heavily weighted towards the prosperity of mankind, would be one that allowed human populations to increase well beyond the natural capacity of the lands and form the very first cities.

The Sumerians founded the city of Uruk in 3,500 BC. The city was dependent on the flooding of the River Tigris and River Euphrates to enhance the fertility of the soils, which allowed food to be grown for its citizens. However, this flooding was unpredictable and therefore led to unpredictable harvests. In response to this, the city constructed the very first artificial landscapes; building a series of large levees to contain the rich waters, which were then distributed evenly to outlying farms through sophisticated irrigation systems (Steel, 2013). By moulding the natural world to suit their needs, the Sumerians could predict their harvests more accurately, enabling them to hold a larger static population and in doing so, establish one the key requirements of civic development. In 3500 BC, city and nature combined to form the 'city-state', exemplifying the connection between prosperity and access to ecosystem services. Today, cities have been freed from the constraints of ecosystem services - with the invention of global trade and the ability to preserve food for long periods of time - making it possible to build cities such as Las Vegas or Dubai in extremely hot and arid environments, or Tromsø or Severomorsk that are well within the Arctic circle. These cities, although lacking access to a sufficient provision of ecosystem services, are far from being the only cities that rely on global trade to sustain their populations. In fact, many cities around the world have now outgrown the local farm belts that initially sustained them.

The disconnection between ecosystem services and cities not only shields urban inhabitants from the vital role nature plays in their lives - leading to extremely attenuated feedback loops between actions and resource use (Campbell, 2009) - but it also separates the key processes that are required to keep people happy and healthy from where they are most desperately needed; i.e. cities. Although the

importation of ecosystem services has become commonplace across the world, it nonetheless has a detrimental effect on the ecosystems that provide them. With the continued migration of rural populations to urban centres, it is likely that the increased demand for food can only be met, at least in the very near future, through the exhaustive use of resources well beyond municipal and national boundaries.

1.2 - The ecological impact of today's cities

In order to better understand the future impacts of cities, the impacts of today's cities must first be understood. The Chartered Institution of Waste Management (Environmental Body) (IWM (EB)) in association with the Greater London Authority, Biffaward, and Best Foot Forward compiled a report in 2002 entitled 'City Limits'. Within this report, the City of London was analysed in great detail to determine its ecological footprint in relation to its geographical area. The report concluded that, by taking into account all perceivable inputs including food, water, energy, transport, materials, and the waste that occurs as a result, the City of London was found to rely on an area 293 times its size (IWM (EB), 2002); which is equivalent to twice the size of the UK. In total, the city of London required 49 million global hectares, with a global hectare described as such:

"[A] global hectare is normalised to the area-weighted average productivity of biologically productive land and water in a given year. Because different land types have different productivity, a global hectare of, for example, cropland, would occupy a smaller physical area than the much less biologically productive pasture land, as more pasture would be needed to provide the same biocapacity as one hectare of cropland. Because world bioproductivity varies slightly from year to year, the value of a gha may change slightly from year to year." (Global Footprint Network, 2012)

Within the report, it was found that each resident of London required the use of 6.63 global hectares of bioproductive land. This demand for bioproductive land is significantly higher than the world's fair land share of 2.18 global hectares per capita, which is estimated to decrease to 1.44 global hectares by 2050 due to

population increase (IWM (EB), 2002). The ecological footprint per capita within the UK is estimated to be 6.3 global hectares (IWM (EB), 2002), resulting in the startling observation that if every human being lived as one did in the UK, three earths would be required to support the world's population. The report concluded that of the 49 million global hectares required to sustain London, it is food that constituted the second largest impact of all activities. The materials needed to supply the city with goods as well as process all of its waste streams accounted for 44 percent of London's ecological footprint, whilst food accounted for nearly the same amount, at 41 percent. The other requirements of a city - i.e. water, transport, energy and tourism - accounted for the remaining 15 percent of the city's impact. Therefore, it can be assumed that London requires 20 million global hectares per year simply to feed its population and those that choose to visit it. This area of land is equivalent to 120 times the size of London's geographic area. When analysing the impacts of food consumption in this way it can be seen that the feeding of cities is an intensive activity and one that puts significant pressure and additional strain on the natural world.

With a growing number of people living in cities, it is the responsibility of all levels of society - from the individual through to municipal and national governments - to ensure ecological footprints gradually reduce, year on year, towards the fair land share of 2.18 global hectares per capita. This will not only help gradually reduce ecological damage, but it will also help ensure that resources are consumed at a closer rate to which they are produced via ecosystem services, or discovered and extracted; minimising peaks and troughs in supply and demand as a result.

If cities are to become more sustainable and resilient to change it is likely that they will have to engage with food at increasingly localised levels to reduce their dependence on global systems, decrease the distance food travels, diminish the need for refrigeration, freezing and packaging and ultimately decrease ecological damage. It is currently assumed that the majority of this localised production in the future will occur in and around cities, and more specifically within or upon buildings. However, the contribution of urban agriculture in delivering any of these goals is currently unknown in many respects due to a lack of large-scale urban agricultural interventions within high-density cities and the lack of communicable knowledge as a result.

1.3 - Why the research is needed

Across the globe, it is becoming a growing concern that biophysical resources will reach peak levels not far from now (Butler 2010; Edwards, et al., 2011). In other words, the production of the chemical compounds that high-intensity agricultural practices rely on will start to decrease, leading to decreased food yields globally. As a result, and in combination with an increased demand for food due to an ever-increasing global population, nations such as the UK, who are dependent on food imports, may find it harder to import the food they need in the future. The simple solution to this is to grow more food domestically, but in the UK this is easier said than done. Currently, 69 percent of the landmass of the UK is already dedicated to agricultural practices, 11 percent is considered 'developed', 11 percent is forest/woodland and the remaining 9 percent consists natural habitats; i.e. grassland, mountains, moors, coastlines and marine environments) (The Office for National Statistics and East Anglia University, 2010). In summary; land that has not already been utilised for agriculture, or that has not already been developed, is protected natural habit such as forest, wetlands and coastlines, which are critical for the provision of ecosystem services in the future. With little to no available land for additional food production in the UK, it is the city where many turn their attention through the integration of urban agriculture.

Urban agriculture aims to grow food within already developed areas, aligning in many ways with agricultural intensification, which seeks to improve food yields year upon year on land that has already been cultivated. Only in the case of urban agriculture the role of 'cultivated' land is replaced with that of 'developed' land. By 2050, the world's population could be as high as 16.6 billion, which is twice as many people as are alive today (ESA, 2013). One way or another, these additional people will need to be fed. However, it is currently unknown if urban agriculture can have any notable impact on domestic food production or whether it is simply a design trend that yields no real benefits. Ultimately, this research is needed because the UK needs to grow more food and urban agriculture is believed by many to be the solution. If indeed urban agriculture is the answer to the shortfall in UK food production, then this is excellent news for the future food security of the nation and the world as a whole. However, if it is not as productive as many thought it would be, other solutions will need to be sought instead of, or in addition to, urban agricultural

integration, dependent on the productivity of urban agriculture to meet the increased food demand of future populations. In an increasingly unpredictable world that is experiencing ongoing climate change, changing weather, accelerated ecological deterioration and increasingly uncertain financial markets, food security will become less and less predictable in years to come. It is not currently known whether urban agriculture can affect this situation, or even if the cities of today can support the integration of agricultural practices, and it is on this premise that the thesis is based.

1.4 - Aims, objectives and research questions

The thesis follows a lineage of inquiry that identifies three key areas of investigation to better understand and quantify the differing impacts of urban agriculture. These key areas are the practical challenges that face the integration of technical food systems within existing buildings, the calculation of UK urban food production and the analysis of additional benefits urban agriculture may afford to urban populations. These key areas of inquiry are referred to as a lineage because each investigation builds upon the last to derive new conclusions. These critical areas of inquiry help generate the three research questions which are identified below.

Research question one

What are the prominent technical challenges associated with integrating technical food systems within existing buildings above ground-level?

The basis and need for research question one is that there are currently knowledge gaps relating to urban agriculture that hinders the development of succinct conclusions to be made as to how easy, difficult, expensive or inexpensive it is to integrate technical food systems within existing buildings. Presently, the technical challenges associated with both ground-level and above ground-level urban technical food systems are widely unknown, due to a lack of effective dissemination. Although both contexts of urban food production need addressing, this research question focuses on the technical challenges associated with above ground-level technical food systems on the basis that it may be possible for an existing building to

support multiple food systems across multiple floors; maximising productivity as a result.

This lack of communicable knowledge will be addressed through a detailed account of the design, construction and commissioning of an elevated aquaponic system - built within an existing building above ground-level - which will provide first-hand empirical knowledge on the issues and challenges that face the integration of technical food systems within existing buildings above ground-level. Although the technical issues encountered as part of this process will be specific to the building itself, it will nonetheless demonstrate whether the integration of technical food systems within existing buildings above ground-level is a simple or complex affair. Additionally, the financial costs of delivering the elevated aquaponic system will also be communicated and discussed to allow meaningful and comprehensive conclusions to be made relating to the future viability of above ground-level food production.

The publication of the design process, schematics, monitoring systems and final working elevated aquaponic system will allow others to critique the design - leading to adaptations and improvements - that will only further improve the success of, access to, and ease of integration of urban agricultural technical food systems in the future. The food production metrics collected from this field research will also allow more accurate calculations to be made when discussing the productive capacity of UK cities. This approach is required to answer research question one because there is currently no other alternative method of accessing, re-appropriating or discovering this knowledge through any other means.

Research question two

What effect, if any, would the large-scale implementation of naturally-lit building integrated technical food systems within inner urban areas have on the food security of the United Kingdom, and how might food produced in this way help mitigate ecological damage?

In order to answer research question two, the agricultural productivity of at least one inner city area within the UK must be known. This agricultural productivity will focus

solely on naturally-lit surfaces and will rely on the combination of light capture data of a UK inner city area - through the use of a computer-generated three-dimensional model - and the metrics of food production secured from the elevated aquaponic system noted in research question one. This light capture analysis will allow conclusions to be made as to how effective UK inner city areas are at capturing light and what proportion of their surface area is capable of supporting the growth of crops. Unlike the design of a technical food system, which can be adapted and improved, cities exist as they are today and are not capable, within the realms of possibility, of being changed to suit urban food production. Therefore, if inner city areas with the UK suffer from too much overshadowing due to the density of building plots, for example, then the arguments for the integration of urban agriculture may be questionable. However, if it is discovered that inner city areas within the UK are indeed capable of supporting crop growth upon most of, or all of, their naturally lit surfaces - i.e. roofs and facades - then urban agriculture could become a prosperous industry.

Once the agricultural productivity of a single UK inner city area is known the data can then be mapped onto all of the other inner city areas within the UK, based on the relationship between the area upon which the city sits and the crops that can be grown per unit area. From this, the total food production of UK inner city areas can be calculated and the impact on UK food security can be estimated, along with any mitigation in ecological damage. Although the conclusions to research question two will not be definitive, due to the assumptions made between one city and the next, it will, however, provide a basis on which future research can be built, and additional benefits can be discussed.

Research question three

What are the potential social and economic benefits of implementing naturally-lit building integrated technical food systems within inner urban areas, and how might these benefits improve human wellbeing within urban environments?

Research question three aims to understand the possible benefits of urban agriculture, in addition to the growing of food, such as the increase in green

infrastructure and the creation of jobs. These two factors, in particular, will be calculated utilising the data generated within research question two; i.e. the productive capacity of an inner city area upon its naturally lit surfaces. This research question will also strive to address the qualitative impacts of urban agricultural integration such as the effects on health and wellbeing. Again, much like research question two, the quantitative data generated within this research question will be a starting point from which future research can be built. For example, the economic model utilised to calculate job creation as a result of urban agriculture within inner city areas will be based upon a simple approach and will not take into account all the complexities that are associated with profit, loss and revenue estimation associated with a large organisation. The data published is therefore intended as a springboard for further enquiry and to promote discussion and debate amongst both advocates and critics of urban agriculture to inform a deeper understanding of the subject and to explore the possible futures of urban life. Unlike the research goals of research questions one and two, the qualitative benefits of urban agriculture, such as any large-scale effects on public wellbeing, cannot be addressed through the building and testing of physical experiments or virtual simulations at this point in time. Instead, the possible advantages of building integrated technical food systems relating to wellbeing will need to be postulated until such a time occurs that there are enough urban large-scale urban agricultural interventions to assimilate the actual benefits of agriculture within cities.

The knowledge generated in answering research question three is a key point of understanding as it will provide an insight into the possible futures of urban agriculture if it was to become a large-scale reality within high-density cities. Understanding the possible social and economic benefits will also allow balanced and well-rounded discussions to take place when considering the future impacts of urban agriculture; creating a counterbalance to the single metric of productivity - which in itself may not be sufficient to instigate change - by including both the qualitative and quantitative impacts of urban agriculture as a whole.

1.5 - Thesis structure

The thesis is primarily divided into background research and experimentation. The background research consists of chapters two, three and four. Chapter two includes an analysis of global food production and the problems that have led to the development of urban agriculture as a proposed method of food production; chapter three includes the definition of the research questions contained within the thesis and the methods that will be employed to answer them; and chapter four classifies the existing methods of urban food production and identifies which may be the most applicable within or upon buildings within high-density cities.

The experimentation portion of the thesis consists of chapters five and six. Chapter five documents the process of designing and constructing an aquaponic system within an existing building above ground-level and chapter six discusses the impact of urban agriculture on UK food security upon naturally lit inner city areas as well as the possible socio-economic benefits of urban farming. The thesis culminates with chapter seven, which includes thoughts and conclusions to the research questions posed and urban agriculture as a whole, with a supplementary chapter identifying future research opportunities in addition to a personal reflection on the research contained within the thesis. A synopsis of each chapter is provided on the following pages, as long with a flow diagram, to provide an overview of the thesis as a whole.

Chapter 2.0 - Global and domestic food

This first chapter is a detailed analysis of the global food system, the food security of the UK and the possibility of urban agriculture as a driver for change. The global food system is responsible for the production and delivery of food to many billions of people the world over. Recently, however, this system has been under increasing pressure to deliver more food to an increased population. The recent food crisis, along with unsustainable agricultural practices have brought the current approach to food production into question and alternatives are starting to be discussed. In a changing world consisting of unpredictable weather, a changing climate and unstable financial markets, food security is becoming a more pressing issue, especially for those countries which import large quantities of food. The quality of and access to food are also becoming increasingly important considerations due to

issues relating to changing diets as a result of high-energy processed foods. In countries such as the UK, where there is very little additional land to grow more or better quality food, it is the city where people are turning their attention to as the future context of food production. Urban agriculture within the UK could be a serious driver for change but currently, this is widely unknown due to a lack of large-scale urban farming examples within high-density cities and the knowledge gaps that have occurred due to poor dissemination.

Chapter 3.0 - Method

Chapter 3.0 identifies the three primary research questions of the thesis and explains how these questions will be addressed and answered. This is achieved through a detailed analysis of design and a comprehensive analysis of research to identify how design and research differ to better understand the ways in which they can relate to one another. The difficulties of architectural design as research is also discussed along with the identification of the different methods of logical reasoning, to draw comparisons between design research and more traditional research methods. Only by understanding the fundamental principles of design and research individually can the two be combined to form applicable research methods for the three research questions. The method for each research question is addressed separately, communicating the method to be utilised by clearly stating the ontological and epistemological position of the method, the scale of applicability - more readily referred to as generalisation - and the type of data to be collected. The tactics employed to answer each research question are also identified, and a detailed overview of the chosen method is also given.

Chapter 4.0 - Urban food production

In order to determine whether existing buildings within high-density cities are capable of supporting the integration of agriculture above ground level, a working urban food system needs to be designed and constructed within said context. However, this can only occur by first understanding the different methods of food production that are available within the urban context. The analysis contained within this chapter presents comparisons between soil-based and soilless agricultural practices, as well as comparisons between the different nutrient delivery systems

associated with soilless food production, such as hydroponic and aquaponic systems. The different techniques associated with soil-based and soilless agricultural practices are also identified, with the help of existing examples, to help draw conclusions as to which methods of agriculture are most applicable within high-density cities, and more importantly, within or upon existing buildings.

Chapter 5.0 - Experiments

One of the primary focuses of the thesis is to understand some of the practical challenges that face the integration of technical food systems within existing buildings above ground-level. This is achieved through the design and construction of a working aquaponic system within an ex-industrial factory in Salford, England. The aquaponic system was designed as part of the Manchester International Festival 2013 and needed to operate simultaneously as both a working urban farm and as a public exhibition. Within this chapter, the design process of this innovative urban farm - from the appointment of Queen's University Belfast to the delivery of the system - is explained in great detail. This includes the design and construction of a small-scale aquaponic system to understand both the technical and biological mechanics associated with such a system, as well as the many design amendments relating to the larger system due to the structural limitations of such a dilapidated building. A novel facade-based aquaponic system was also delivered as part of the festival due to receiving first-stage funding from the Technology Strategy Board, which is again discussed and analysed. Collectively, the large-scale aquaponic system and the facade-based aquaponic system allow conclusions to be made relating to both the productivity of building integrated technical food systems and the challenges that hinder their integration above ground-level, thereby answering research question one.

Chapter 6.0 - Future integration

In this chapter, the final two research questions are addressed; relating to both the impact of urban agriculture on UK food security through the integration of naturally lit technical food systems within inner city areas, and the possible socio-economic benefits of urban agricultural integration as a whole. The data relating to the impact of urban agriculture on UK food security will be generated through the combination

of light capture analysis - to determine the capability of high-density cities to support crop growth - and the productivity metrics of both the horizontal and vertical aquaponic experiments to calculate the productive capacity of a single city. This data can then be mapped onto the remaining UK cities to generate a broad understanding of the impact of urban agriculture on UK food security. Once the productivity of a single city is determined, figures such as economic value, job creation and mitigation of ecological damage can also be calculated. The final section of this chapter addresses the possible social and economic benefits of agricultural integration within high-density cities and discusses how these might affect the psychological, physiological and financial wellbeing of urban populations.

Chapter 7.0 - Conclusions

The final chapter of the thesis is where the conclusions of the research are documented. The three research questions act as the primary structure of the chapter; whereby each research question is reiterated, along with a brief description of the method employed to answer the question, a summary of the knowledge acquired, and the presentation of the conclusions reached. After each research question has been concluded, chapter 7.0 brings together all the knowledge captured within the thesis to arrive at some final thoughts relating to urban agriculture as practice, the future of building integrated technical food systems, and the many impacts urban agriculture can have across a number of sectors.

Chapter 8.0 - Future work and reflection

Supplementing the thesis is an additional chapter which gives an opportunity to address some of the shortcomings of the research, which can be addressed through future research in areas relating to technical food systems, light capture analysis, biocyclical urbanism and the social aspects of urban agricultural integration. Finally, there is an opportunity for the author to give a short personal reflection on the knowledge contained within the thesis, the delivery of the aquaponic food system and the future of urban agriculture and building integrated technical food systems.

Table 1.1 - Thesis flow diagram

Background and Method	Urban food production and Experimentation	Simulation and Conclusions
<p>The environmental damage and socio-economic impacts associated with global food production</p> <p>↓</p> <p>The increase in global population, the recent food crisis and the challenges of future global food production</p> <p>↓</p> <p>Achieving food security in the United Kingdom</p> <p>↓</p> <p>The possibility of urban agriculture as a solution to domestic food security</p> <p>↓</p> <p>The current lack of communicable knowledge associated with many aspects of urban food production</p> <p>↓</p> <p>The definition of three primary research questions</p> <p>↓</p> <p>The chosen method of inquiry to answer each research question</p> <p>↓</p> <p>(continue to urban food production and experimentation)</p>	<p>(continuation from background and method)</p> <p>↓</p> <p>The contamination of native urban soils</p> <p>↓</p> <p>The opportunities and constraints of soil-based agriculture within high-density cities</p> <p>↓</p> <p>The opportunities and constraints of technical food systems within high-density cities</p> <p>↓</p> <p>The opportunity to experiment as part of the Manchester International Festival</p> <p>↓</p> <p>The concept design of a novel aquaponic system above ground-level</p> <p>↓</p> <p>The design and construction of a small-scale aquaponic system</p> <p>↓</p> <p>The design and construction of a building integrated aquaponic system above ground-level</p> <p>↓</p> <p>The design and construction of a vertical facade-farm</p> <p>↓</p> <p>(continue to simulation and conclusions)</p>	<p>(continuation from urban food production and experimentation)</p> <p>↓</p> <p>The light capture analysis of the city of Manchester, England</p> <p>↓</p> <p>The contribution of naturally-lit building integrated technical food systems to the food security of the United Kingdom</p> <p>↓</p> <p>The impacts of building integrated technical food systems on the health and wellbeing of urban populations</p> <p>↓</p> <p>The knowledge acquired and conclusions arrived upon as a result of the three research questions</p> <p>↓</p> <p>The opportunities for future work</p>

1.6 - Original contribution to knowledge

Through design-decision and simulation research, along with logical argumentation, the thesis advances knowledge in urban agriculture and building integrated technical food systems by making the following original contributions: 1) documented practical challenges of integrating an aquaponic system on the top floor and roof of an existing building, 2) considerations related to the future placement of technical food systems within existing urban environments, 3) productivity of both horizontal and vertical aquaponic systems within existing buildings, 4) proportion of the surface area of high-density cities that can support the growth of crops, 5) calculation of food production, economic value and job creation as a result of naturally lit urban agricultural systems within UK cities, 6) estimation of the cumulative contribution of urban agriculture within inner city to UK food security, 7) environmental savings as a result of urban agricultural within inner city areas, 8) possible social and economic benefits to urban populations as a result of urban agriculture within high-density cities.

2.0

G L O B A L

A N D

D O M E S T I C

F O O D

2.0 // GLOBAL AND DOMESTIC FOOD //

In the previous chapter, the aims and objectives of the thesis were identified, which included the formulation of three research questions. These research questions relate to the technical challenges that face the integration of agriculture within cities above ground-level, the impact of urban agriculture within inner city areas on UK food security, and the effects urban agriculture may have on urban populations in the future. However, in order to progress with these research objectives, the issues that have led to the development of urban agriculture as a possible method of large-scale food production need to be better understood. This chapter, therefore, analyses global food production, food imports and food security as the primary forces that are driving the need for alternative methods of food production, such as urban agriculture, in an ever-changing and less predictable world.

2.1 - An overview of the global food system

The global food system, also known as the food supply chain, is a unified term for the people, businesses, and corporations that are needed to take food from the point of sowing to the point of consumption. The food supply chain has seen fundamental changes in recent history due to violent geopolitical reorganisation, which led to the end of imperial colonialism; reshaping the way food is grown and traded as a result (Friedmann, et al., 1989). This reorganisation of the global food system led to the increased production of food, the increased trade of food, and the increased scale of operations. Consequently, the governance of the global food system has become extremely complex and multi-scaled, involving a multitude of private, public and civil stakeholders (Lang, et al., 2009). Today, the global food system has become so complex that the need for global governing bodies, such as the Food and Agricultural Organisation of the United Nations, are required to monitor the efficiency and applicability of the global food system as a whole and, where possible, identify and remedy gaps in food access. The creation of global governing bodies led to an increased awareness of global food production and resulted in the ‘feed the world’ ideology. This new ideology identified that in fact, food production was falling short of

what was required by the world's population at that time. In many ways, this led to the 'green revolution', which refers to an intense period of research and development, during the 1960s, relating to the intensification of food production; i.e. increasing food production without cultivating new land.

Between 1961 and 2007, the world's population doubled, but agricultural production nearly tripled. The green revolution fueled this production increase with new varieties of crops, improved application of pesticides, herbicides and fertilisers, and improved rural infrastructure and water management (Mazoyer, et al., 2006). During this period, agricultural land area expanded by only 11 percent from 4.51 to 4.93 billion hectares, and arable area grew by only 9 percent from 1.27 to 1.41 billion hectares (FAOSTAT, cited in Royal Society, 2009). Global food consumption, as an average, also increased as a result, from 2280 kcal per capita per day to 2800 kcal per capita per day (Pretty, 2012). The agricultural gains associated with the green revolution have helped millions of people escape poverty and starvation and has provided a platform upon which rural and urban development has been built on. Norman Borlaug, who was the driving force behind the green revolution, received the Nobel Peace Prize in 1970; credited with saving over a billion people from starvation. However, there is now widespread acceptance that, despite significant advances in agricultural science and technology leading to increased food production, there have been unintentional consequences, both socially and environmentally, of these achievements.

2.1.1 - Environmental impacts of food production

The environmental damage caused by the current global food system is evident across the world. For example, it is estimated that 1.7 million hectares of Amazonian rainforest is lost to farmland each year and a staggering 20 million hectares of existing arable land is lost annually due to salinisation and soil erosion as a result of intensive exploitive agricultural activities (Steel, 2013). In other parts of the world, many commercial fish species are becoming economically extinct. That is to say that the population of some species are now so low that fishermen cannot catch enough to make a profit. It is now believed that 63 percent of global fish stocks need intensive management to rebuild populations and diversity due to continuing exploitation (FAO, 2005). Collectively, the agricultural sector is estimated to produce

one-third of global greenhouse gas emissions, which is twice that of the transport sector (IPCC, 2007), drawing attention to the severe impact agricultural activities have upon the environment.



Figure 2.1 - Destruction of Amazonian rainforest for cattle pasture

As a result of these actions, agriculture has become the primary cause of loss of biodiversity - at the genetic, species and ecosystem level - across the world. Key practices, which exacerbate this loss, are the increased use of synthetic pesticides, herbicides and fertilisers, the cultivation of new land that was once forest or wetland (Green, et al., 2005), the reduction in marginal and uncropped habitat areas, land homogeneity due to increased use of monocultures and the reduction of fallow periods that would otherwise help revive spent soils (Robinson, et al., 2002; Wilson, et al., 2009). Collectively, these effects - i.e. excessive resource use, exhaustion of land and pollution of the environment - are referred to as negative externalities as they impose costs upon the planet which are not reflected in the market price of food items (Baumol, et. al., 1988; Dobbs, et al., 2004; Pingali, et al., 1995; Norse, et al., 2001; Tegtmeyer, et al., 2004; Pretty et al., 2005). These hidden costs, once known, shift conclusions regarding agricultural efficiency and asks questions about which food systems are in fact more efficient and cost-effective in the long run. The costs

associated with these negative externalities will at some point in the near future need to be repaid to guarantee future food production for generations to come.

2.1.2 - Social and economic impacts of food production

The social implications of the global food system are equally degenerative and can have a huge effect in a very short space of time. The green revolution brought about a focus on income generation and export rather than sustenance and self-sufficiency, which when combined with biased free trade can lead to substantial problems. For example, agricultural producers in developed regions such as the United States, Europe and Australia all promote free trade but at the same time subsidise their farmers. Producers in the developing world, on the other hand, are persuaded to grow high-value crops for export, but can sometimes struggle to compete economically with crops produced within developed regions, and as a result, farmers within developing regions are left with perishable crops that they cannot sell. This cycle leads to increasing debts amongst farmers in developing countries, who become impoverished and undernourished as a result (Butler, et al.,2012). The increased productivity associated with the green revolution also accelerated nutrient depletion within soils and decreased plant resilience, due to specialised breeding, which also brought about an increased reliance of farmers on fertilisers, herbicides and pesticides. This reliance on additional inputs and resources did not only put further economic pressure on some farmers but it also severely damaged the ecosystems supporting agricultural practices and negatively affected the health of both those producing food and those consuming it. In some cases, countries have become so entrenched in the global food system that they now export the majority of their food for economic gain and have to then import food for sustenance. Such is the case in The Gambia, which exports nearly all of its rice to foreign markets, and in doing so, has become entirely dependent on rice imports to feed their population (Butler, et al.,2012).

As a result of the green revolution, however, agricultural productivity has soared. In between the two world wars, the gap between the most efficient and least efficient producers in the world was approximately 900 kilograms of food per worker per year. By the end of the twentieth century, this gap had increased to 200,000 kilograms of food per worker per year, and today the very best equipped, very best situated, and

very best proportioned farms can produce nearly 2,000,000 kilograms of food per worker per year more than the least efficient farmers in the world. As a result of this increased productivity, the cost of food has fallen, in some instances, by up to 75 percent (Mazoyer, et al., 2006). These increases in productivity, however, have still not solved the global food problem of alleviating world hunger. In fact, over half of the world's population is still described as 'hungry' whilst nearly a quarter of the world's population is overweight (Dybas, 2009), which has led to growing concerns regarding dietary diversity and the nutritional content of foods.

2.1.3 - *Changing global diets*

Analysts and commentators within agricultural and climate fields are already concerned that the quality of diets are deteriorating. In today's world, so many are reliant on so few that the knowledge of what makes food *food* is being lost. Over the last fifty years, food supply chains have become increasingly connected and extended, which has led to foods of questionable nutritional value not only becoming universally accessible but also widely acceptable and affordable to a large proportion of the world's population; due primarily to the prevalence of supermarket chains (Blouin, et al., 2009). Michael Pollan (2008, p.7) argues that the 'food we're consuming today is no longer, strictly speaking, food at all, and how we're consuming it - in the car, in front of the TV, and, increasingly, alone - is not really eating'. To counter this trend, Pollan suggests that one should not eat anything that one's grandmother wouldn't recognise as food; drawing a critical comparison between food production and food consumption today and the same only two generations earlier.

The pervasiveness of supermarket chains has steadily gained momentum over the past thirty years, with the locus of power gradually shifting down the food supply chain, to the supermarkets themselves as a result (Vorley, 2003). It is now estimated that three-quarters of all food sales in most industrialised countries pass through supermarket checkouts. More worryingly is that this trend is becoming increasingly prevalent in developing countries as well (Reardon, et al., 2008). This shift in power raises concerns relating to nutritional content and dietary diversity (Hawkes, 2008) as well as concerns relating to the environmental implications of decision makers that are in no way connected with the ecosystems that produce the food that is sold.

Nutritional deficiencies due to poor dietary diversity and food quality are expected to rise as a result of expanding food supply chains around the world and increased economic prosperity. Today, close to two billion people suffer from serious iron, vitamin A and iodine deficiencies along with a number of other vitamins and minerals (Mazoyer, et al., 2006). As a result of these deficiencies, the pressure on healthcare institutions will increase as a result (Royal Society, 2009). In general terms, good nutrition is dependant on the consumption and absorption of two principal food elements; caloric energy and essential macro and micronutrients (Butler, et al. 2012). When the correct levels of these elements are consumed, good health and wellbeing will follow.

The increasing demand for meat is also a growing concern, both environmentally and physiologically, due to the growing economic prosperity of both developing and developed countries. Meat consumption in China, for example, has doubled between 1989 and 2009 and is expected to double again by 2030 (Scherr et al., 2009). Meat consumption in the UK was reported to be 83.7 kilograms per capita per annum in 2015 (Agriculture and Horticulture Development Board, 2016) - compared with just 25 kilograms per capita per annum only a century before (Steel, 2013) - and meat consumption in the USA is expected to reach 115 kilograms per capita per annum not far from now (Royal Society, 2009). Collectively, meat consumption is projected to grow from 229 million tonnes in 1990 to 465 million tonnes by 2050 (IAASTD, 2009a). The primary issue with meat consumption is that it takes between eleven and seventeen calories of food to produce one calorie of meat (Smil, 2002). Due to this, it is estimated that one-third of all food is currently being diverted to the production of meat (Millstone, et al., 2003; Steinfeld, 2006). Taking the UK as an example, only seven percent of the per capita consumption is meat based, but the production of this meat requires 49 percent of the total land required per person per year (Agriculture and Horticulture Development Board, 2016; de Ruiter, et al., 2016). Milk consumption is also expected to rise from 580 million tonnes to 1043 million tonnes by 2050 (Steinfeld et al., 2006). As a result of this increased demand for meat and dairy products, the volume of food diverted to animals increases, decreasing food access around the world, and previously uncultivated land needs to be cultivated in order to provide the much needed grazing area to meet the demand. The increased consumption of red meat and dairy, when combined with an increased consumption of sugar, fat and salt - the primary ingredients in many

modern high processed foods - is likely to lead to the growing prevalence of obesity, type two diabetes and chronic pulmonary diseases across the globe, as well as a number of other noncommunicable diseases.

2.1.4 - Population and the challenges of future food production

As a result of population increase, the availability of agricultural land per capita has reduced significantly. In 1970, 0.38 hectares of global agricultural land was available per person. In the year 2000, this value had greatly reduced to 0.23 hectares and by 2050 this figure is expected to reduce to 0.15 hectares per capita (FAO, 2012). This decrease in land share means that a single hectare of agricultural land will need to supply enough food for 6.7 people per annum in 2050, whereas the same area of land in 1970 had only to produce enough food for 2.6 people (FAO, 2012). Despite significant growth in food production over the past fifty years, it has been estimated that food production will need to increase by between 70 and 100 percent by 2050 to meet global food demand without any significant increase in price (FAO, 2009a; Godfray, et al., 2010). More worryingly is that it is estimated that there is enough food produced globally to calorically feed the world (IAASTD, 2009b; Watson, 2012), yet over one billion people still go to bed undernourished every single day (Watson, 2012). Simply put, the increases in food yields have not made significant impacts on food access or reduced global poverty, the root causes of global hunger (Sen, 1981). The challenge of meeting this enormous increase in food production is not only a daunting task, but the issues related to the feeding of a nine billion world are compounded when the demands of the seven billion world cannot be met today. Climate change is also expected to affect all facets of global food production and food security in the future including but not limited to decreased food quality due to soil nutrient depletion, toxin accumulation in crops affected by excessive heat and/or rain, decreased food yields due to adverse weather, and decreased accessibility and availability due to spoilage in adversely warm or wet weather (Butler, 2010; Edwards et al. 2011, Butler, et al. 2012). Complicating matters even further is the increasing competition for land due to biofuel production - regardless of the ongoing debate surround its actual environmental savings (FAO, 2008; Searchinger, et al, 2008; Fargione, et al., 2008) - and the effects food crises can have on the world's population; such as the food price spikes of 2008, which pushed between 100-150

million people into malnutrition (Watson, 2012) and also led to social and political instability.

2.1.5 - The recent global food crisis

The monetary inflation of basic foods represents the very worst aspect of the transition of food into a commodity, where its value is calculated on its potential to return on investment, with no recognition of its importance as an essential element of human life. As such, its price is variable much like any other traded product and can be affected by a multitude of different events, pressures and drivers. In the past, there have been periods of time where food has increased in price, but the events between 2005 and 2008 set a new precedent. Before this, there was a strongly held assumption that, at a global scale, hunger was the result of environmental disaster, conflict, or the regime of a despotic ruler. Another strongly held assumption was that, as a global community, the production of sufficient calories and the commitment of responsible governments to uphold the objectives documented in the Millennium Development Goals in combination with the Universal Declaration of Human Rights surely indicated that solving global hunger was on the horizon. Along with aid from individual nations and the creation of new institutions such as the WTO (World Trade Organisation), which helped expand free trade, a mechanism was created, which many believed would rid the world of hunger. However, these assumptions came to an abrupt end during 2005 through to 2008.

Starting in 2005 and peaking in 2008, the world saw a sharp increase in the cost of food as the food index grew by an average of 57 percent (FAO, 2009b). This price spike led to so called 'food riots' in Africa, Asia, South America and the Caribbean as a result of food scarcity and even the resignation of the prime minister of Haiti due to social upheaval. In total, there were protests in over thirty countries. Some governments reacted poorly to these protests - arresting and jailing people in countries such as Morocco, Mauritania and Burkina Faso, and even killing protesters in Cameroon and India (Rosin, et al., 2012). As a result, organisations such as the World Bank and the Food and Agricultural Organisation of the United Nations pushed for a rapid response. The events of 2005 through to 2008 were referred to as a crisis; not because a billion people were still starving, but because of the social and political instability that occurred as a result of food insecurity.



Figure 2.2 - 2008 food riots in South Africa

The underlying drivers affecting food prices are extremely complex and the food crisis was seen by many as a 'perfect storm'. This terminology, however, put the blame firmly in hands of fate. Robert Watson (2012), in contrast to this, identifies many of the fundamental issues that affected food production and food sale during this time and how these may have contributed to the food crisis, which can be seen below:

- poor harvests due to climate change and increasing variability of weather conditions such as the Australian drought
- population increase and an increase in urbanisation
- an increase in demand for less efficiently produced foods from growing economies such as China
- the increasing use of food for fuel such as the production of bioethanol from sugar and maize
- increased price of the inputs to agriculture such as pesticides and fertilisers
- protectionism of significant exporters to protect domestic consumers such as India, Ukraine and Argentina
- increased trading of food due to a lack of confidence in other financial markets as a result of the economic downturn within the same period

- import tariffs and export subsidies which will also have played their role in the events preceding the crisis by distorting global markets.

The food crisis forced food system analysts to re-examine the interconnections between food production, a rapidly changing climate, volatility of financial markets, the potential end of plentiful oil, and the competition of agricultural land for the production of biofuels. It also brought attention to the error of relying on cheap food as a driver for continued economic growth and the falsified assumption of guaranteed cheap labour as a result of cheap food in developing countries (Rosin, et al., 2012). Regardless of whether one, all, or a combination of the factors noted above led to the food crisis, the fundamental question is whether this was a momentary blip or a harbinger of the future. The adverse effects of weather can be short-lived whereas longer-term issues relating to the rising cost of energy or the tipping point of climate change may give rise to more enduring problems surrounding food production, trade and access. The impact of climatic extremes, as a result of anthropogenic climate change, in areas such as Vietnam, Russia and Australia during 2007 and 2008, suggest that issues of food scarcity and food insecurity may become much more common in the future as the world's weather and climate become less predictable. One thing is for certain, however; a crisis occurred because there is something wrong with the current approach to global agriculture. Food critics agree that these current methods cannot continue to be employed as a way of securing food for future populations, without the threat of a crisis occurring again - or as Tim Lang suggests 'the crisis in 2005-8 was not a blip, but creeping normality' (2010, p97).

2.1.6 - The future of the global food system

In summary, the current approach to global agriculture demands an extraordinarily high cost from the environment and the societies that both support it and depend on it. Although the caloric needs of the world could be met with revised strategies regarding food access, it is still unclear whether the nutritional requirements of the world could be met in the same way due to a need for differentiation between feeding the world calorically and feeding the world nutritiously (Hawkesworth, et al., 2010). The combination of climate change, contradicting ideologies of free trade, along with a range of resource peaks generally inhibits the ability of the global food

system to provide for each and every person and ultimately predicts tough times ahead if the 'business as usual' model of food production is sustained based on the assumption of infinite resources.

In order for the global food system to meet future food demand, simply producing enough and making food accessible today is not in itself a long-term solution, as future food systems will also have to negotiate a multitude of differing and ever-increasing pressures. A recent analysis of the top 100 global questions for agriculture and food systems (Pretty, et al., 2010) identified common drivers, which will affect the outcome of food security during this century. These identified themes and challenges demonstrating the interconnected socio-ecological nature of food systems and determined that solutions will need to come from varying spheres of technological, political and economic influences; i.e. energy and resilience, climate change and water use, social capital and gender, biodiversity and ecosystem services, consumption patterns, food supply chains, power and policy making, and governance (Pretty, 2012). Despite the emergence of many technological and scientific advances over the past fifty years, the combination of these key drivers pose unprecedented and novel challenges for global agriculture, which is under increasing pressure to ensure food production and food security utilising methods that are both socially and environmentally sustainable. (IAASTD, 2009a; Godfray, et al., 2010; National Research Council, 2010; Sachs, et al., 2010).

It is believed that the goal of achieving affordable, accessible and nutritious food in a sustainable manner is possible although 'nothing short of a new agricultural revolution' with 'a more rational use of scarce land and water' will guarantee this (Watson, 2012, p.xii). Only an approach that simultaneously considers ecological remediation, climate change, energy policy and food policy will ensure a future global food system that delivers healthy, nutritious food to all (Butler, et al., 2012). However, all this needs to be achieved when the increases in productivity year on year slows for staple cereals around the world, when competition for water from other sectors is growing, when agricultural soils are continually degrading and becoming exhausted, when competition from biofuels is increasing, when biodiversity is being lost at all levels, and when the climate is becoming ever more unpredictable, collectively increasing the number and severity of spikes that will occur in the future (Watson, 2012).

2.2 - Achieving food security in an uncertain world

Food security is the combination of three key drivers that must be adequately realised to secure food for a known population. These key drivers are the quantity of food that is produced, the quality of food that is provided and access to a sufficient volume of food. In simple terms, food security is only fully achieved when there is enough food to go around that is of sufficient quality to ensure the nutrient needs of those that consume it. Realistically, neither access or quality can be achieved without sufficient quantities of food to feed the masses, but quantity alone does not guarantee quality or access. These key attributes of food security will be discussed below, along with the two primary methods of producing more food, the ongoing debate regarding the ability of locally produced food to improve quality and the possibility of sustainable food production to help achieve food security in the future.

2.2.1 - Access to food

Access to a sufficient volume of food is one of the most complex aspects of food security due to unpredictable global markets and the many agents involved in the growing, distribution and sale of food. As previously mentioned, it is estimated that the global food system already produces enough food in caloric terms to feed the existing population even though half of the world is defined as hungry, with a billion people suffering from malnutrition. On the other side of the economic spectrum over one billion people find themselves in an environment where food is accessible but may not carry sufficient nutrients. As a result, over 23 percent of the world's population are considered overweight and 10 percent obese (Dybas, 2009). This, therefore, draws attention to the maldistribution of global food and the differing effects it can have on developed and developing countries. Although the issues relating to food access are complex, they can be remedied to varying degrees by growing more food domestically and reducing the reliance on imported food.

2.2.2 - Quantity of food

When discussing food security, the focus quickly turns to the amount of food produced; i.e. maximising the production of calories, proteins and vitamins. The underlying argument for a volume driven food system is that if enough food is

produced, the market will ensure that each person is sufficiently fed, and hunger will be a thing of the past. However, recent events will prove this has not been the case. To guarantee improvements in food yields year on year, labour must decrease as a result of improved technology, and the use of input resources must reduce. However, the reliance on the quantity of food alone to guarantee food security makes some large assumptions about the physical world; referred to as 'virtual realities of farming' (Van der Ploeg, 2009, p.19). These 'virtual realities' primarily assume that yields and profits will increase year on year, with access to an unlimited supply of natural resources. It is only when these yield increases are not met that so-called 'anomalies' arise; leading to decreased productivity, decreased profits or economic loss, which results in reduced access to food. Traditional agriculture ultimately relies on finite resources and the expected increase in yields is now known to be reducing year on year. Most worryingly is the fact that grain yields are improving at slower rates, with rice yields improving at the slowest rate of all crops types. With regards to maize, any improvements in yields are being diverted to biofuel production (Butler, et al., 2012). It is now becoming a concern that biophysical resources will reach peak levels not far from now (Butler 2010; Edwards, et al., 2011). In addition to the assumptions made by a quantitative approach to food security, as well as the environmental and social impacts previously mentioned, agricultural practices focused on maximising production can also have unexpected consequences.

During the green revolution 'miracle rice' was developed to improve rice yields while decreasing inputs. This was achieved by reducing the overall size of the plant and shifting energy use into the edible areas of the crop. This development led to the widespread use of miracle rice throughout Asia, which not only drastically reduced biodiversity - from thousands of species of rice to just a handful - but also led to deficiencies in vitamin A for those eating miracle rice (Stock, et al., 2012). Vitamin A is a fat-soluble nutrient and is essential for a healthy immune system, eyesight, and individual linings of the body (NHS, n.d.). The response to this was genetically engineered 'golden rice', with additional beta-carotene; a nutrient which can be converted into vitamin A by the body. Although golden rice only provided one percent of a human's recommended daily consumption of vitamin A, it was seen as a success due to the ability of technology and science to at least provide a solution, regardless of how small the contribution was of that solution (Shiva, 2000). Not only

did miracle rice and golden rice drastically reduce biodiversity and the resilience of a staple food that many in Asia relied upon, but due to the fat-soluble nature of vitamin A, many of those undernourished were unable to access the one percent of their recommended daily intake. In light of these adverse effects, miracle rice and golden rice significantly improved rice yields, and many people went to bed fed, at least calorically, as a result.

It is now known by many commentators that global food production will need to increase substantially in the coming decades to meet the demands of population growth (World Bank, 2007; IAASTD, 2009a; Royal Society, 2009; UNEP, 2010; Godfray et al., 2010), but there remain very different views as to how this increased food production should be achieved. There are two primary methods that are currently utilised across the globe to grow more food. These strategies are intensification; improving yields through the increased use of monocultures, improved application of improved pesticides and herbicides, and improved modern synthetic fertilisers, which aim to maximise production; and extensification; the process of cultivating new land to grow more food. There is a third option, which includes the genetic engineering of crops but advancement in this field has done very little to improve yields, and in reality, genetic engineering has reduced yields through a phenomenon known as 'yield drag' (Gurian-Sherman, 2009). The intensification of agricultural practices has been the central cause of the decline in ecosystem services and has simultaneously increased the production of greenhouse gases and reduced levels of carbon sequestration (UNEP, 2010). Extensification of agricultural practices, on the other hand, is the leading cause of loss of biodiversity due to the conversion of natural habitats, such as forests and wetlands, into farmland (Green, et al., 2005).

Whether additional food is grown through intensification or extensification, ecological and environmental damage still occurs. The long-term viability of both strategies and their implementation is also a concern. Intensification, by definition, is 'an increase in agricultural production per unit of inputs' (FAO, 2004, p.3). Intensification, therefore, seeks to either, maintain levels of production through the progressive decreasing of inputs, or, improve levels of production through sustained levels of inputs. Although improved efficiencies within food production metrics are a good thing in the short term, it is not a long-term solution due to the reliance of agricultural production on

the extraction and use of fossil fuels and minerals. Extensification in many ways is the far more destructive strategy as it sees natural habitat, which provides many of the ecosystem services upon which humans rely, converted into cultivable land. However, in today's world, and as destructive as the process of extensification is, there is increasing competition from other sectors for land such as residential and commercial development, solar capture, biofuel production and even production of food for the benefit of other countries. Over recent years, China has bought up tracts of land in Africa to help meet its demand for food and fuel (Spielfeld, 2009), allowing them to acquire the rights to grow palm oil on 2.8 million hectares of Congolese land, for example (The Economist, 2009). Additionally, in regions that have not experienced recent agrarian reform, such as Latin America, South Africa, Zimbabwe, Ukraine and Russia, there are swathes of inaccessible land due to large privately owned estates that cover several thousand to tens of thousands of hectares. When high-value agricultural land is utilised for purposes other than food production as a result of increased competition or remains inaccessible due to historic or despotic land ownership, additional land has to be cultivated elsewhere, which is usually of lower agricultural value, leading to the production of lower quality foods.

2.2.3 - Quality of food

The quality of food does not only apply to how nutritious food is - i.e. the consumption of micro and macronutrients - but it also encapsulates the dietary diversity food can offer, the way food is grown or reared - such as organic agriculture and free-range livestock - , the cultural significance of food and the social cohesion brought about by food; either through its production, trade, preparation or consumption. To put this in more concise terms; 'through food, things like culture, community and identity are created, enacted and reinforced' (Stock, et al., 2012, p.119). The quality of food also extends to the knowledge transfer from one group to another, whether those groups are culturally or generationally different. The 'slow food' movement is one example of the working practices related to a qualitative food system, which celebrates local knowledge and diversity, regional and national foods, as well as the deep cultural connections between people and food, inclusive of its preparation and consumption by social groups, which all help sustain cultural knowledge, history, tradition and practices (Stock, et al., 2012).

When discussing the quality of food the question being asked is ‘what is food?’; i.e. what is it made from and what does it represent to different people. Food is not merely a carrier of calories, and neither is it simply a commodity. Therefore, food needs to be categorised and discussed differently. Organic farming, and the practices associated with it are the obvious counterweight to traditional mass agriculture. The focus of organic, permacultural, agroecological and biodynamic food production begins with nutritious food that is grown in an ethically, environmentally and ecologically sound manner, that respects the soil and the people that depend on it for sustenance and livelihood (Stock, et al., 2012). The inherent qualities of food are all the ‘things’ that make food socially, culturally and politically meaningful as well as nutritious and wholesome. Often, the views of a qualitative food system involve a turn towards local production. However, this assumes that there is an inherent link between ‘local’ and ‘quality’, which is not always the case. This can be referred to as the ‘local trap’ (Born, et al., 2006, p.195), which refers to...

“...the tendency of food activists and researchers to assume something inherent about the local scale. The local is assumed to be desirable; it is preferred a priori to larger scales. What is desired varies and can include ecological sustainability, social justice, democracy, better nutrition, and food security, freshness and quality...the local trap is the assumption that local food is inherently good.”

The idea of globalised trade as a ‘bad thing’ has only recently entered the consciousness of the general public, due to concerns over the distance food travels to sit on a supermarket shelf. For many, global food production is ‘bad’ and local food production is ‘good’. Defining the local in this way prevents any critical discourse from taking place and analysing these assumptions. It is known that the global food system is responsible for mass ecological and environmental damage, but there is nothing to say that food cannot be produced in the same unethical and ecologically damaging way closer to home. Similarly, large-scale food production is often considered to be ‘bad’ whereas small-scale agriculture is considered to be ‘good’. Again, these assumptions prevent critical analysis from taking place to determine to what extent these assumptions are true or false. Paul Stock and

Michael Carolan (2012, p.122) describe their experiences with small and large-scale farming in the following manner:

“...we’ve both seen small farms managed terribly (and those products were loaded into the back of a gas-guzzling pickup truck and driven a hundred miles to a large farmer’s market) and large farms managed brilliantly (and those products were consumed with a 15 mile radius)”

Local food production can reduce food miles and can reduce and reverse ecological damage but ultimately, the farming practices that are utilised and the location of the point of sale need to reflect these ambitions.

It should also be noted that the quality of food, and the way it is produced, processed and consumed ultimately drives people's decision as to what they will and will not eat, regardless of quantity or access. This can be eloquently summarised by the 2002 food aid incident where the US sent a large quantity of food aid to southern Africa. The food aid that was given to southern Africa was in the form of whole corn kernels, but after it arrived on African soil, it became known that the food aid contained genetically modified organisms (GMOs). The recipients of the food aid were not made aware of this before the shipments were sent and the delivery of food was rejected. The US was outraged that any country would reject food when their people were starving but this essentialises the role quality plays in the food security debate as Jacques Ellul (1990, p.53) explains:

‘We must not think that people who are the victims of famine will eat anything. Western people might, since they no longer have any beliefs or traditions or sense of the sacred. But not others. We have thus to destroy the whole social structure, for food is one of the structures of society.’

Ultimately, quantity, quality and access form the three pillars of food security but brokering the right combination of these three components to meet global food demand is not easily achieved. Some believe it is possible to achieve the goal of delivering affordable, nutritious food for all in an environmentally sustainable manner, but also note that this will not be achieved through the utilisation of the current global food system. Instead, it is believed that nothing short of an

'agricultural revolution' is required to make better use of scarce land and water resources (Watson, 2012). A revolution that simultaneously considers and consolidates food policy, climate change policy and energy policy into to roadmap of development for the future (Butler, et al., 2012). Food is not simply a commodity but a fundamental element of human existence.

2.2.4 - The ideology of sustainable intensification

The closest ideology the world currently has to a balanced net zero ecological approach to agriculture is 'sustainable intensification'. This method of agriculture shares the same ethos as its less developed counterpart 'intensification', but with the added component of ecologically sound practices. In the 1990s the idea of sustainable intensification gained momentum in response to African agricultural practices, where environmental degradation was a growing concern and yields were usually very poor (Reardon, et al., 1996). Today, the term is used extensively as a springboard to discuss sustainable agricultural practices around the globe, thanks in part to the publication of 'Reaping the Benefits' by the Royal Society in 2009. According to the definitions presented relating to sustainable intensification (Pretty, 2008; Royal Society, 2009; Godfray, et al., 2010; Conway, et al., 2010) a sustainable food system would; utilise crop and livestock varieties that exhibit high productivity to input ratios; avoid the unnecessary use of external inputs; minimise or avoid where possible the use of technologies or production methods that adversely affect human health and the environment; make use of human capital to innovate, adapt, share knowledge and social capital to resolve widespread issues; minimise the production and impact of negative externalities such as the production of greenhouse gases, toxification of water sources and destruction of biodiversity; and lastly utilise agro-ecological practices to assist in nitrogen cycling, beneficial allelopathy, beneficial predation, biological nitrogen fixation, and beneficial parasitism.

Although the aims of sustainable intensification are well founded, it does not, as an ideology, provide any concrete answers on how these goals may be achieved. This leads many to criticise the approach of sustainable intensification for its lack of clarity and lack of defined ecological goals. Sustainable intensification is therefore seen more as a description of agricultural practices already in place that can be adapted to meet future challenges, rather than an aspirational plan of action; i.e.

identifying how food should be grown in the future. There is also scepticism about the practice of intensifying production sustainably and ecologically. In the past, when crop yields have increased rapidly - primarily during the industrial revolution and green revolution - the ecological damage associated with this increased food production has been massive. Therefore the term 'sustainable intensification' is seen as a dichotomy, rather than a realistic strategy. In the world today there is already enough food to go around, which has been discussed previously, so the estimated need to grow up to 100 percent more food to cover a 28.5 percent increase in the human population more than anything draws attention to the other issues driving the global food system such as food loss, food waste, governance, and public attitudes to food.

Ultimately, much of the world now understands the environmental consequences of the global food system as a whole, and are aware of the vital role ecosystem services play in the everyday life of every living creature on the planet. Hence, the need to intensify production sustainably is required to reduce the need to cultivate new land elsewhere, and in doing so reduce further damage to the biosphere. However, in some countries such as the United Kingdom where nearly 80 percent of the land mass has already been altered to suit the needs of its population and with a profound reliance on food imports, the real question is will the improvements in food yields and ecological restoration brought about by sustainable intensification or an agroecological approach alone be enough to secure the future of a small island off the coast of Europe with regards to food production?

2.3 - Food security of the UK

As the world becomes more globalised, the demand for food will be increasingly met through the use of resources well beyond the boundaries of each nation. In 2014, it was estimated that almost a quarter of all food produced for human consumption was traded internationally (D'Odorico, et al., 2014) and that 20 percent of global agricultural area is utilised to support this international trade (Kastner, et al., 2014). It can, therefore, be seen that the world has become reliant, in many ways, on the global trade of food; greatly affecting food security for those nations that import the majority of their food. With a relatively high population density - 266 people per

square kilometre (ONS, 2015) - the UK, like many other developed countries, is dependent on food imports - inclusive of potable liquids and livestock feed - to sustain its population.

In 2016, food and agricultural imports to the UK amounted to £47.5 billion, of which £33.6 billion, or 71 percent, originated from EU countries. The most imported product category at this time was animal protein, followed by fruits, vegetables & flowers, consumer foods, and beverages (Smit, et al., 2017). In 2008, the UK was reported to be 'about 60 percent self-sufficient' (The Cabinet Office, 2008, p.viii). However, this was only when foods destined for export was included in the calculations. In fact, only 49 percent of the food consumed in the UK was produced domestically (The Cabinet Office, 2008) at this time. Between 2008 and 2017, the debt of the UK increased by 121 percent from £785 billion to £1.731 trillion (ONS, 2017). As a percentage of GDP, this equates to an increase of 38.8 percent from 50.2 percent in 2008 to 89 percent in 2017. With a reliance on imported foods and growing national debt, the UK is in a precarious situation. That is to say that in the future the UK may not be able to secure the food it needs due to further increased economic debt, the inflation in the price of food or a rise in protectionism as a result of poor global harvest.

When considering nourishment, shelter, mobility, goods and services the ecological footprint of the UK is estimated to be three times its size, requiring 321,621,000 global hectares to sustain its population (Stockholm Environment Institute, 2003). Similar figures can also reinforce agricultural dependence to a similar factor as 67 percent of the total agricultural land required to feed the UK is located abroad (de Ruiter, et al., 2016). If every person on the earth lived as one did in the UK, three earths would be needed to supply demand indefinitely. This impact corresponds to 6.3 global hectares per capita, which is in striking contrast to the fair land share per capita of 1.8 global hectares (WWF, 2012). This dictates that the UK's ecological footprint needs to decrease by at least 71 percent to live in equilibrium with the replenishment of natural resources and the projected discovery of finite resources. Foods which are subjected to global trade typically flow from high-yield countries to low yield countries, with ecological damage and gaseous emissions flowing in the opposite direction. In essence, the UK is not only importing the majority of its food, but it is also exporting its ecological damage across the globe.

2.3.1 - The ecological impacts of UK food demand

The dependence of the UK on international trade to meet its food needs has increased substantially between 1986 and 2009; increasing from 20.2 million tons per year to 33.9 million tons per year; a rise of 68 percent. Due to the successes of agricultural intensification, however, the total agricultural area relating to UK food demand has increased at a much slower rate from 8.9 million hectares in 1987 to 10.9 million hectares in 2008. The agricultural land share per capita in the UK is now 0.18 hectares per annum. This expansion can be attributed to an increase in the domestic population of approximately five million people, as well as an increase in consumption per capita during the same period. Again, between 1986 and 2009 food consumption in the UK has grown from 56 million tons per year to 71 million tons per year, with food consumption per capita growing from 985 kilograms to 1148 kilograms per year; an increase of 17 percent. The total availability of caloric energy per capita per day in the UK - i.e. the sum of consumption and waste - has also vastly increased from 5522 kcal in 1986 to 6892 kcal in 2009 (de Ruiter, et al., 2016).

Nourishment - inclusive of the consumption and absorption of sufficient caloric energy and essential macro and micronutrients - accounts for 28 percent of the total ecological impact of the UK; requiring nearly 92 million global hectares to keep the UK population fed and watered (Stockholm Environment Institute, 2003). In 2013, the UK food industry alone accounted for 8.7 percent of the total carbon dioxide equivalent production in the UK - estimated to be 55.8 million tons of CO₂e of the total 643.1 million tons of CO₂e produced per year (ONS, 2013). The entirety of food consumption as a whole within the UK, accounts for close to 115.8 million tonnes of CO₂e, accounting for 18 percent of the total carbon dioxide equivalent production in the UK (The Cabinet Office, 2008). The greenhouse gas emissions associated with the use of manure and fertilisers, along with rice production and land use change - i.e. the emissions produced when cultivating new land - for the area required globally by the UK has increased from 19.1 Mt CO₂e in 1987 to 21.9 Mt CO₂e in 2008. Land use change accounts for the lion's share of these emissions at 64 percent, with fertiliser use contributing a further 24 percent, and manure application and rice cultivation adding 6 percent and 5 percent respectively (de Ruiter, et al., 2016).

Based on these figures, the UK is now emitting 62 percent of its agricultural carbon dioxide equivalent abroad with South America (18 percent) and European Union (15 percent) taking the brunt of these increased greenhouse gas emissions as a result of increased reliance on imported foods (de Ruiter, et al., 2016). Globally, agriculture now accounts for approximately 40 percent of land use (Foley, et al., 2011), and the agriculture and forestry sector is responsible for just under a quarter of global anthropogenic greenhouse gas emissions (Smith, et al., 2014). The Food and Agricultural Organisation of the United Nations reports that 28 percent of global arable land is used annually for the production of food that is either lost or wasted (FAO, 2013). Within the UK this food waste equates to approximately 16 million tonnes per year at a cost of £22 billion per annum (Waste & Resources Action Programme, 2011). The UK is, in essence, paying to waste food, waste energy, and damage the environment unnecessarily through the intensive industrial activities which are needed to feed its population.

2.3.2 - Land use and future food security in the UK

The actions needed to prevent further ecological deterioration as a result of the intense agricultural and industrial activities required by the UK to feed its population, as well as addressing issues relating to food security, lay primarily in the ability to produce more food domestically, in addition to wasting less. However, these actions are in no way simple. The Office for National Statistics and East Anglia University (2010) note that 69 percent of UK land is already utilised for agriculture, with 11 percent of land considered to be developed, 11 percent as forest/woodland and the last 9 percent left to other natural habitats, such as grassland, mountains, moors, coastlines and marine environments. Increasing food production is a difficult challenge in any region, but in countries such as the UK, where the majority of accessible land is already farmed, it is difficult to foresee how this increase in food production will manifest without further irreversible damage to depleting natural habitats and ecosystem services.

There are three primary options available to the UK to grow more food domestically. These options are to grow more food on the land that is already cultivated via further agricultural intensification, cultivate new land within the UK for agriculture as a result of agricultural extensification, or grow food on already developed land via urban

agriculture. With only marginal gains to be made and a range of resource peaks, as well as biophysical peaks, occurring not far from now, agricultural intensification cannot be relied on to deliver the food demands of the UK. Additionally to this, only a fifth of the UK land mass is still categorised as natural habitat, and where possible this needs to be preserved to ensure the provision of ecosystem services for future generations. Hence, urban agriculture is seen to be the only solution to an impending UK food crisis, whereby the food security of the nation is improved through the integration of agriculture within cities. It seems as though urban agriculture could be a viable solution to increased domestic food production but very little is known about this practice within high-density cities, such as London, Manchester and Birmingham for example. Therefore, it is difficult to determine to what extent the integration of urban agriculture would contribute to domestic food production, and whether its integration is feasible or economically viable at such large urban scales.

2.4 - Urban agriculture as a solution to future food security

In simple terms, urban agriculture is the practice of producing and distributing food right in the heart of cities (Cockrall-King, 2012). This definition, however, can be extrapolated to include the cultivation of both crops and the rearing of animals, to provide food and natural fibres, through marketing and distribution, in built-up or intra-urban areas (Thornton, 2012). The broader term for this practice, when encompassing food production on the fringes of cities is 'urban and peri-urban agriculture'. 'Urban agriculture' and 'urban and peri-urban agriculture' ultimately describe very similar practices, however, the context of the latter includes the entirety of urban areas - from the centre to the edges - whereas the prior focusses on food produced primarily in the centre of cities. Regardless of the context, both urban agriculture and urban and peri-urban agriculture are seen to be a holistic and low-energy response to ecological damage and global warming (Roseland, 2005), as well as food and nutrition insecurity within poor households (Dreschel, et.al, 2010). It is, therefore, anticipated that the large-scale integration of urban agriculture will be capable of simultaneously responding to multiple issues, such as reducing the consumption of fossil fuels and other inputs, reducing waste flows, improving the self-sufficiency of cities, and improving the dietary diversity of those most affected by

poor food access. From these drivers, two distinct groups of motivations come into focus - i.e. as a response to ecological damage and waste or the need for sustenance and nutrition - that can generally be categorised as the impetus for the implementation of urban agriculture within developed countries and developing countries respectively. In both instances, the goal is to improve food security, improve self-sufficiency and improve the lives of those who grow it, engage with it and consume it.

In order to achieve any of these benefits, urban agriculture has to respond to some key difficulties, which are not typically associated with traditional agriculture. These challenges include, but are not limited to, unique constraints such as legality, land tenure, pollutants and access to light; practical functionality, such as husbandry, harvesting, income and employment; and the spatial planning of the practice, which typically responds to the availability of space whether it be a terrace, rooftop or vacant building plot (Thornton, 2012). Due to the availability of space within urban centres, the practice has to be capable of integrating with the built environment in a multitude of different ways, as well as be capable of responding to a number of drivers such as local socio-economics, politics, population density, geography and climate. As a result, a multitude of contextually fit-for-purpose systems manifest, which can not only increase the resiliency of any large-scale urban food system but can also lead to fast prototyping and innovation.

Due to the impetus for the integration of food production within cities, the need for contextual design and the resulting benefits brought about by the practice, urban agriculture is seen as the intersection of ecology, design and community as a dialogue to invite food back into the city and reconnect and engage people with their local and regional food systems, to promote a healthier and more sustainable lifestyle (Philips, 2013).

2.4.1 - The reintroduction of urban agriculture

Despite the origins of agriculture in and around cities, dating back to the first cities of Uruk, Ur, Larsa and Nippur, the phenomenon of urban agriculture did not re-emerge as a potential formal solution to global food security until the 1970's. This is not to say that urban agriculture did not exist in modern times before the 1970s, but simply

that urban agriculture gained popularity during this time, leading to its serious consideration as a method of food production. The World Commission on Environment and Development (WCED) later produced the 'Brundtland Report' in 1987, which focused the world's attention on sustainable urban development and the potential role of agriculture within cities (p.254):

"...urban agriculture could become an important component of urban development and make more food available to the urban poor. The primary purpose of such promotion should be to improve nutritional and health standards of the poor, help their family budgets (50-70 percent of which is usually spent on food), enable them to earn some additional income, and provide employment. Urban agriculture can also provide fresher and cheaper produce, more green space, the clearing of garbage dumps and the recycling of household waste."

Despite the publication of the Brundtland Report - which championed urban agriculture as a lifeline for the 'urban poor' both in terms of sustenance and income generation - attempts to formalise urban agricultural have struggled to negotiate the constraints associated with its integration both environmentally; such as issues relating to waste, pollution and pests; and institutionally; including issues relating to health, politics and land ownership.

In the western world grassroots movements - including community agricultural concepts (Adam, 2006) and the production and distribution of locally grown food through community gardens and fully-fledged urban farms - have played a key role in formalising urban agriculture as a larger part of both urban planning and sustainable agricultural policy (Hopkins, 2000). Increasing domestic food production not only reduces the amount of food that needs to be imported - simultaneously reducing food miles, refrigeration, freezing and packaging - but it also reduces the need to cultivate new lands elsewhere to meet growing food demand, along with reducing food waste at the source and the point of sale through reuse, recycling and composting. Due to this, urban agriculture is viewed by many as a comprehensive response to global warming, ecological damage and food insecurity.

However, this utopian view of urban agriculture is not shared across the world. Many developed and developing regions in the global south see urban and peri-urban agricultural activities as unsightly and in some instances can even be banned for fear they reflect the country in a poor light (Tinker, 1994). This stigmatises urban agriculture as an anti-modern and unprogressive tradition that many cities have spent decades trying to remove in the goal of achieving 'cleanliness'. In the global north, local production can be viewed as a regressive temporary use of space; favouring the development of large cold-store warehouses and improved heavy-goods routes to improve food access (Lawson, 2016). Despite these barriers to the integration of urban agriculture some municipal governments, such as Dar es Salaam (Tanzania), Kaunda (Zambia) and Harare (Zimbabwe), that recognise the importance and positive impacts of urban agriculture - primarily the nutrition and dietary diversity brought about by urban agriculture - are actively exploring ways to integrate urban and peri-urban agriculture into formal planning policy (Dreschel, et al., 2010; Thornton et. al, 2010) and are calling for better provisions of local food to aid in improving food security (Nel, et al., 2009).

2.4.2 - Urban agriculture in practice

The most extensive urban farming food systems are commonly found where access to resources - both financial and physical - are diminished, and geographical or political separation restricts access to markets both for exports and imports. Within the northern hemisphere, the more extensive urban food systems exist within areas that have experienced rapid industrial decline, and as a result, population decline and skill redundancy, such as in Detroit and Chicago. In the southern hemisphere, Cuba is probably the best known example of this, however, the factors affecting the integration of urban agriculture here were far more severe. The collapse of the former socialist trading bloc in 1989 and the resulting termination of oil imports from the former USSR led Cuba to a food and energy crisis known as Cuba's 'special period in a time of peace' (Rosset, et. al, 1994). The lack of access to petroleum drastically reduced the country's capacity to export their input-dependent monocultures - predominantly sugar cane - which drastically reduced the country's ability to afford and import the required inputs for farming. The food security of the entire nation was compromised and led to the official support of urban and

peri-urban agricultural initiatives across the country as part of a wider strategy to produce organic and sub-organic foods (Thornton, 2012).



Figure 2.3 - Soil-based urban agriculture in Chicago, USA

Elsewhere in the global south, many newly independent and developing nations borrowed heavily from foreign lenders in the 1970s, in an attempt to finance social and public safety-net expenditures such as food subsidies. Austerity measures, also known as ‘structural adjustment programmes’, created by the International Monetary Fund and executed by the World Bank, sought to educate developing nations in fiscal responsibility by demanding the liberalisation of their markets and insisting that all safety-net expenditures be diverted to paying off foreign debt. This often led to the removal of food subsidies which had severe and lasting impacts on the urban poor to meet their nutritional needs. In most cases, the removal of such a vital lifeline forced the hands of many to start growing food immediately, in whatever space was available. As a result, urban and peri-urban agriculture expanded quickly as an alternative strategy for meeting the demand for low-cost food. The practice of urban agriculture in response to food insecurity within nations negatively affected by

structural adjustment programmes is well documented (Rogerson, 1993; Thornton, 2008) and demonstrates the effectiveness of urban agriculture in helping to meet at least a proportion of urban food demand in a short period of time. Ultimately, urban agriculture is a local response to economic, environmental, social and political crises to keep food continually affordable and available (Thornton, 2012).



Figure 2.4 - Soil-based urban agriculture in Havana, Cuba

In addition to food production, informal income generation and employment, urban agriculture is being discussed in culturally diverse and geographically contrasting places. For example, peri-urban agriculture is being implemented in Mexico City to combat unauthorised urban sprawl (Torres-Lima et al., 2009; FAO, 2014a). The 'suelo de conservación' is an area that was created in 1992 to protect the city's vital ecosystem services; including forests, grasslands, wetlands and 300 km² of farmland. In places such as Hyderabad, Pakistan (Van Rooijen, et al., 2010) and Accra, Ghana (Cofie, et al., 2006) urban and peri-urban agriculture is being utilised to better deal with wastewater treatment as a result of rapid urban population growth. In contrast to the approach of neoliberalism to agriculture - i.e. the

widespread use of monocultures destined for export and reliance on a fossil fuel economy - urban agriculture is positioned as an effective strategy for not only dealing with food insecurity, but also as a way to address other issues facing urbanity, such as urban sprawl, wastewater treatment, and income generation.

2.4.3 - The future of urban agriculture

Aside from examples such as Cuba - which is reliant on the provision of vacant space at ground-level - urban agriculture has only been proven at a number of small-scales. Moreover, within high-density cities the integration of urban agriculture exists only as a handful of very small interventions, when considering the areas cities occupy and the food they require. These interventions, although very worthy proofs of concept, have very little communicable knowledge associated with them relating to initial costs, productivity, upkeep, and financial performance, for example.

In order to demonstrate this, an extensive search was conducted to determine the knowledge that was readily available for three well-known building integrated technical food systems. These projects included Lufa Farms in Montreal, which is a rooftop hydroponic system consisting of a large open greenhouse on top of an existing building; Urban Organics in Minnesota, which is a ground floor aquaponic system within an old brewery; and Sky Vegetables in New York, which is a rooftop hydroponic system within a greenhouse that was built as part of a new development. These three examples cover a broad range of contexts such as existing and new buildings, rooftop and ground floor locations, as well as accounting for both hydroponic and aquaponic systems, which will be discussed further in chapter four. The basic information that was searched for included the productivity of the food system, initial cost, running costs, energy use, the weight of the system, building alterations required to accommodate the system and to see if any detailed drawings were available. Searches were made via the Google scholar, the Queen's University Belfast Library digital catalogue (including online journals), Science Direct and Researchgate. Almost no mention was made to any of the cited examples and none of the basic information was found on any of these academic platforms. An internet search was then conducted which did provide some of the basic information required. It should be noted, however, that this information is not peer-reviewed and may not be accurate. It is also not made clear whether the cost associated with the

different projects includes the purchase of the building and whether the productivity per unit area includes for space utilised by the entire project or only that of crop growth. The findings of this search can be seen on the following pages.



Figure 2.5 - Lufa Farms, Montreal

Lufa Farms - Montreal

Description	Rooftop hydroponic food system
Productivity	57.4kg/m ² per annum (Immen, 2013)
Initial cost	\$2,000,000 (£1,400,000 estimated) (Immen, 2013)
Running cost	<i>unknown</i>
Weight	19.4kg/m ² (Immen, 2013)
Energy use	<i>unknown</i>
Building alterations	Two staircases to the roof and a small freight elevator (Immen, 2013)
Detailed drawings	<i>no information available</i>



Figure 2.6 - Urban Organics, Minnesota

Urban Organics - Minnesota

Description	Ground floor aquaponic system
Productivity	7.8kg/m ² and 3,600 fish per annum (Painter, 2015)
Initial cost	\$1,000,000 (£700,000 estimated) (Moore, 2013)
Running cost	<i>unknown</i>
Weight	<i>unknown</i>
Energy use	<i>unknown</i>
Building alterations	<i>unknown</i>
Detailed drawings	<i>no information available</i>



Figure 2.7 - Sky Vegetables, New York

Sky Vegetables - New York

Description	Rooftop hydroponic system built as part of new building development
Productivity	80kg/m ² per annum (Dawson, 2013)
Initial cost	<i>unknown</i>
Running cost	<i>unknown</i>
Weight	<i>unknown</i>
Energy use	<i>unknown</i>
Building alterations	not applicable
Detailed drawings	<i>no information available</i>

Based on the information presented, it can be seen that there are many gaps in the knowledge available relating to building integrated technical food systems, even for systems that are well-known. It can also be seen that the productivity of the three systems - based on available information - varies substantially per unit area per annum. In addition to this, the lack of design information, such as drawings and schematics, for example, makes it impossible to understand how any of these technical food systems operate and how they were integrated and realised; making it almost impossible to replicate such systems in other contexts without starting from first principles. Ultimately, the lack of communicable knowledge makes it difficult to determine whether or not such an approach to food production would be economically viable at a large-scale, or to predict and foresee the challenges that would face the integration of such systems. Therefore, many question the efficacy and ability of urban agriculture to address such issues as rising food demands on a global scale within high-density cities because there is simply not enough information available for solid conclusions to be made at this point in time.

Although urban agriculture is in the early stages of a renaissance, some describe the farming of local organic produce as a utopian solution to global food security, pushing it to one side because it does not conform to tradition and established methods of agriculture. However, its strengths are worth considering and exploring to obtain the true impact of the practice. Paul Stock and Michael Carolan (2012, p.114) summarise the typical view towards local organic produce as a solution to global food security as follows:

“To boil it down to its core, the argument often goes something like this: the problem of global food security needs science-based solutions, not pie-in-the-sky theories - ‘people live off fish not fantasies’ to adapt the famous proverb. That’s the critique, at its heart, that conventional agriculture directs at the competing alternatives (organic, local, etc.): that they are too long in the latter (values) and too short in the former (facts). Or, to sum up the critique in one word, such competing visions are - gasp - utopian”.

By definition, all the proposed solutions relating to global food security are utopian because they all express different ways in which food ought to be grown to meet

demand. All possible solutions require the same rigorous testing and trials to ascertain their positive effects, negative effects and ultimately their impact on food production and food security. As mentioned previously, urban agriculture is not simply a food delivery system as it can alleviate a multitude of different urban pressures and can reinforce cultural identities and social interactions - something industrial food could never profess to achieve. Urban agriculture may even find itself in a position, in the future, to be able to impart knowledge on upcoming generations and teach them the methods and values of agriculture; possibly alleviating issues relating to ageing agricultural workforces and driving forward new and innovative ways of producing food.

Urban farming represents such a radical departure from traditional agriculture that proponents of a quantity led food system give it little thought, if any at all. However, vertical farms have inspired the imagination of designers across the world (Despommier, 2011) who have brought the idea of agriculture and food security to a younger audience; i.e. the people who will be growing food in the future. These striking designs manifest as a succession of high-rise towers filled with lettuces or livestock that take on multiple forms throughout cities across the world. This in itself is no bad thing; the issue of food security needs to be understood by a wider audience, and the world needs younger people to get excited about farming, but herein lies at least part of the philosophy surrounding the view that urban agriculture is utopian in its execution. So far, there has been very little, if any, movement in constructing the first skyscraper full of lettuces to test its feasibility and this is more than likely due to the rather unappealing economic model such a project presents. Regardless of this, new designs continue to appear on design trend websites, and architectural magazines, documenting the so-called new future of food production. The integration of farming with architecture has indeed captured the imagination of many thousands of people but, due to the lack of communicable knowledge, the world is still awaiting for the construction of the first vertical farming tower.



Figure 2.8 - Farmscraper towers by Vincent Callebaut Architects

2.4.4 - The need for urban agricultural inquiry

Not only is it difficult to believe in something that has not been sufficiently tested, but the idea of urban and vertical farming does not sit well with those holding onto romanticised images of agriculture; as it entirely decimates the collective ideologies of rurality, nature and agriculture, and the imaginary Venn diagram that connects them together. There is a stark contrast between the cold technological appearance of westernised urban agriculture and the romanticised views of an invented past (Stock, et al., 2012); such as the paintings by Thomas Sidney Cooper, Charles Jones and most famously by John Constable in the mid-1800's. If these romanticised views can be pushed to one side, even briefly, the potential benefits of urban agriculture can be identified, analysed and critiqued in a fair manner. Although not agricultural in nature, there are well established urban landscaping and architectural projects that help share a vision of how nature can be successfully integrated with today's cities and the built form such as at the High Line in New York designed by Diller, Scofidio and Renfro (see figure 2.7), and the Bosco Verticale

towers in Milan designed by Boeri Studio (see figure 2.8). These biophilic approaches to design are only a small step away from the integration of agriculture within high-density cities and proves that more realistic approaches to the integration of nature with cities - through the combination of public, private and commercial initiatives - can provide meaningful opportunities for people to engage with nature, as well as providing the possible locations for future food production and the provision of improved ecosystem services.



Figure 2.9 - The High Line by Diller, Scofidio and Renfro in New York, USA

Ultimately, agriculture has to be commercially driven and economically successful to exist in a neoliberal world; high yields and economic returns are what make agriculture possible. Furthermore, the very idea of agriculture in the city helps the bridging of deeply entrenched dichotomous beliefs within the modern world that the urban and the rural are incompatible, or that the global and the local are two separate entities which seldom interact. Urban agriculture affords urban populations the opportunity to engage with nature while growing food and creating jobs. However, the current communicable knowledge available relating to urban

agriculture within high-density cities does not provide enough clarity to allow decisions to be made on the applicability and impact of urban agriculture as a whole. Therefore, the next generation of urban food systems at the medium-scale and large-scale are seldom developed past the conceptual stage due to a lack of understanding and a lack of support at local, regional and national levels as a result.



Figure 2.10 - Bosco Verticale towers by Boeri Studio in Milan, Italy

3.0

METHOD

3.0 // METHOD //

In the previous chapter the impacts of the global food system, both environmentally and socially, were identified, along with the need for the world to grow more food due to population increase. In countries such as the UK, however, where there is little to no additional land in which to grow food, and a heavy dependence on food imports, it is the city which many see as the context of future food production. There is currently divided opinion as to the real-world impact of urban farming with regards to food security, and there is very little communicable knowledge about the challenges that face the integration of food production within today's cities. It is these issues that drive the thesis and the formation of the research questions. Within this chapter, the method of investigation relating to these research questions will be determined and identified through the comparison of traditional and design-based research methods.

3.1 - Problem definition and research objectives

In chapter two there was an analysis drawn between the motivations driving the integration of urban agriculture in developing countries and the motivations driving the integration of urban agriculture in developed countries. These different motivations, ultimately, generate different approaches to urban agriculture. For example, urban agricultural practices in developing regions are primarily the result of pervasive food poverty and the need to feed family members utilising whatever materials come to hand. Such agricultural practices can manifest at many different scales - from food systems that occupy a terrace or balcony up to those that occupy entire building plots - and will typically utilise soil-based methods. Urban agriculture in developed countries, however, is a far more relaxed affair, with the impetus firmly set on reducing food miles, improving food security and decreasing ecological damage; or simply as a pastime or hobby. The methods of urban food production in developed regions still utilise soil-based systems in raised bed community gardens, for example, but there is also an opportunity to expand into technical or 'soilless' food systems as a method of increasing productivity at the expense of higher initial start-up costs. Regardless of whether traditional soil-based practices or more

experimental soilless systems are employed, the scale of production in developed regions is typically small due to the lack of motivation to grow large quantities of food and the limiting factors of the urban environment, such as a lack of available space as a result of high building density. Taking Cuba as an example, the need for food production was so great, due to the collapse of the communist trading bloc, that vacant building plots were given over to agricultural practices in order to strengthen food production within the country and improve food security. What Cuba has achieved is nothing short of exemplary and it is a true success story of urban agriculture at a large scale. However, the successful integration was dependent upon access to space that might not be so readily available in high-density cities.

Without an impetus to grow more food domestically in countries such as the UK, due to that lack of any actual or perceived food crises, it is unlikely that land in high-density cities such as London, Manchester or Birmingham would be allocated to the growing of carrots, potatoes or lettuces at ground-level when building developments can achieve far greater returns on investment. Hence, 'space' is a resource many cities within developed countries have little of, or so it might seem. Within post-industrial cities access to ground soil - or 'space' - has been gradually reduced over nearly two hundred years due to ongoing development. This, however, presents an interesting opportunity for urban agricultural integration due to the increased surface area of cities as result. For example, if a four storey building is placed on a 10 metre wide by 10 metre long site, with a floor to floor distance of 3 metres, the original area of site will have been increased by 100 square metres per floor plate, 100 square metres due to the roof, and 120 square metres per exterior wall; totalling 980 square metres and increasing the surface area of the site by 880 square metres. This additional surface area creates opportunities to grow food within the building itself or upon the exterior walls or roof; improving the potential productivity of the land through a multitude of modern and innovative techniques. Due to a lack of readily available space within high-density cities in the UK, the methods utilised by Cuba to develop large-scale soil-based urban food systems are less applicable and, therefore, other methods of food production need to be sought if urban agriculture is to make any significant impact on domestic food production.

3.2 - New methods of agriculture within high-density cities

As mentioned in the previous chapter, there are many ambitious urban agricultural concepts that have captured the minds of the masses, which promise to deliver vast quantities of local food, in tall purpose-built edifices to help improve food security, minimise food miles, decrease ecological damage and reduce the use of fossil fuels. However, such an approach within high-density cities would require the demolition of existing buildings to create the space required, massive expenditure and urban upheaval, along with unjustifiable levels of embodied energy, in order to grow food. As a result, this approach can only be viewed as a poor strategy for food production within urban centres at this moment in time. A more appropriate strategy would be to work with cities as they exist today rather than against them; growing food within or upon existing buildings, thereby mitigating the need to demolish buildings and create new ones.

In order to do this, food systems need to be placed within or upon buildings, which requires an entirely new approach to food production that simultaneously reduces weight, whilst maximising productivity. Such methods of food production already exist in the form of hydroponic and aquaponic technical food systems, which typically utilise plastic trays to grow food directly in nutrient-rich water. Currently, there are very few constructed examples of large technical food systems within high-density cities and the majority exist on the ground floor or rooftops of existing buildings; i.e. they only utilise a fraction of the increased surface area of the site, tending to avoid the entirety of exterior walls and internal floor plates. Furthermore, the heuristic insights acquired through the design and construction of these systems, along with the knowledge generated relating to cost, productivity and energy use, in addition to maintenance considerations, are typically left uncommunicated - as illustrated in the previous chapter - due to the lack of systematic research goals from the outset and poor dissemination.

Due to the small number of constructed technical food systems within high-density cities and the lack of communicable knowledge associated with them, it is currently very difficult to not only analyse, critique, and ultimately improve upon the design and output of any known system, but also to identify and understand the technical difficulties associated with growing food in this way. Collectively, these issues create

barriers to the progression and understanding of urban agriculture as a whole. As a result, any ecological or social benefits which arise as a result of the integration of urban agriculture within high-density cities are also difficult to quantify at this moment in time.

It is, therefore, critical to improve the quality and accessibility of knowledge associated with urban agriculture within high-density cities, focusing on how urban food systems can be integrated at ground-floor level, intermediate floor level, roof level, and on facades of existing buildings to address the technical difficulties of their integration, the cost of such endeavours and ultimately, the productivity of such systems. The creation and dissemination of this knowledge will ultimately allow conclusions to be made relating to the validity of growing food within our urban buildings as an appropriate method of large-scale agriculture within high-density cities, the impact that food produced in this way could have on domestic food production and food security, the ecological benefits of large-scale agriculture within high-density cities and the economic viability and social benefits associated with this integration.

3.3 - Main research questions

With only a handful of very small - in agricultural terms - key examples of technical food systems within high-density cities, it is very difficult to determine the technical challenges of integrating such systems within the existing built environment, the impact such systems can have on food security and the possible social benefits agricultural integration can have within today's cities. These issues, which are deemed to be the pressing questions currently associated with the practice of urban agriculture, are focused on throughout this thesis and help derive the three research questions that inform the structure of the research. The three research questions are noted below, along with a brief explanation to define the position and importance of each inquiry in relation to the progression of urban agricultural knowledge. The proceeding sections will then address, in greater detail, the exact methods to be utilised in answering the three research questions as part of a broader analysis of design and research.

3.3.1 - Research question one

What are the prominent technical challenges associated with integrating technical food systems within existing buildings above ground-level?

As mentioned previously, there are currently knowledge gaps associated with urban agriculture that hinders the development of succinct conclusions to be made relating to how simple, complex, expensive or inexpensive it is to integrate technical food systems within existing buildings in high-density cities. Presently, the technical challenges associated with both ground-level and above ground-level technical food systems - i.e. systems within buildings that exist on the first floor or above - within high density cities are widely unknown due to the small number of functional systems within this context and the poor dissemination of the knowledge acquired during the design and construction phases of their commissioning. Therefore, it is difficult for most - apart from those that have built these systems previously - to understand the difficulties associated with integrating food systems within existing buildings on the ground-level or above ground-level. Although both these contexts of food production - i.e. ground-level and above ground-level - need addressing, this research question focuses on the technical challenges associated with above ground-level technical food systems on the basis that it may be possible for an existing building to support multiple food systems across multiple floors; maximising productivity as a result. The generation of knowledge associated with this research question will provide an improved understanding of urban farming and its integration within today's high-density cities, which will ultimately allow conclusions to be made as to whether integrating technical food systems above ground-level is complex and expensive, simple and inexpensive, or whether it falls somewhere between these two extremes. Regardless of where the generated knowledge falls upon this spectrum - of costly and complex through to cost-effective and simple - the conclusions formed will provide much needed information and data that will ultimately shape urban food systems in the future.

In many respects, urban agriculture can be thought of as a positive initiative, that single-handedly responds to many different issues simultaneously, both locally and globally. However, if there are multiple barriers that stand in the way of it's large-scale integration within high-density cities then this needs to be communicated

in order to instigate further research and to potentially reduce the complexity and cost of integration, in order to gain improved clarity relating to the impacts of the practice. Reciprocally, if the process is one that is simple and cost-effective, then this also needs communicating in order to address any myths that surround the practice, and to promote the increased density of these systems; again, to improve clarity relating to the impacts of urban agriculture. It is on this basis that research question one is crucial to the future understanding of urban agriculture and the lineage of inquiry that is contained within this thesis relating to building integrated technical food systems.

3.3.2 - Research question two

What effect, if any, would the large-scale implementation of naturally-lit building integrated technical food systems within inner urban areas have on the food security of the United Kingdom, and how might food produced in this way help mitigate ecological damage?

Research question two confronts the current lack of information relating to the impact of building integrated technical food systems on domestic food security and the mitigation of ecological damage as a result. In order to address this, it is critical to understand the productivity of such systems within high-density cities in order to be able to calculate, with improved accuracy, their productivity across the UK and to determine how this productivity may affect food security and ecological savings. As illustrated in the previous chapter, there is information available relating to the productivity of building integrated technical food systems. However, this information varies substantially and does not appear in peer-reviewed papers or journals. The information provided is also ambiguous because it does not state clearly whether the productivity per unit area accounts for the areas occupied by crop production only or the area utilised by the whole project; which would include the space utilised by ancillary equipment, such as areas for germination, or walkways to access the system, which would ultimately decrease the productivity per unit area of the project. Although food can feasibly be grown anywhere with the use of artificial light and access to water and nutrients, research question two focuses on the impact naturally-lit technical food systems - i.e. food systems within facades and upon roof spaces - could have on domestic food security and ecological savings as a result of

widespread integration. This is due to the reduction in energy use of naturally-lit systems when compared to artificially-lit systems, which are typically dependant on fossil fuels to produce food.

The data generated as a result of answering research question two will allow a greater level of accuracy to be achieved when calculating the productive output of naturally-lit building integrated technical food systems within individual cities and the UK as a whole. This will ultimately allow conclusions to be made relating to the future impacts of building integrated technical food systems on UK food security and to determine whether this productivity yields any ecological savings as a result.

3.3.3 - Research question three

What are the potential social and economic benefits of implementing naturally-lit building integrated technical food systems within inner urban areas, and how might these benefits improve human wellbeing within urban environments?

The final research goal of the thesis aims to understand the potential social and economic benefits of implementing naturally-lit building integrated technical food systems within high-density cities. Typically, the benefits of urban agricultural integration relating to those that work with urban food systems and depend on them for employment, as well as those that passively engage with them on daily basis are generalised in favour of discussing the more pressing impacts of urban agriculture in more detail, such as food production and the possibility of minimising food imports. However, in cities in developed countries - where levels of depression and anxiety are rising despite improved standards of living - it is clear that the urban environment currently provided as a result of development and investment is not synonymous with maintaining or improving levels of wellbeing amongst those that live and work within them.

The integration of naturally-lit building integrated technical food systems and the improved provision of ecosystem services, as a result, could lead to improved health and wellbeing with urban centres. However, it is not currently known to what extent this integration may, or may not, affect the health and wellbeing of urban inhabitants.

Research question three, therefore, aims to better understand the potential benefits of urban agricultural integration within high-density cities such as the increase in green infrastructure, the improvement in urban diets, the creation of jobs, the reduction of air pollution and the benefits provided to the local economy. The generation of this knowledge will enable improved conclusions to be drawn relating to the value of the practice as a whole, rather than simply stating the metrics of food production. For example, if food production within cities is discovered to be relatively low but the social capital that is generated as a result is high, the simple question of 'how much food does urban agriculture produce?', becomes more complex, to the point where urban food production may help save money elsewhere due to the improvement in people's health and wellbeing. This deeper understanding is something that is currently missing in many debates relating to urban agriculture.

3.4 - Scope and limitations

The information contained in this thesis covers many different scales - from individual components that create working urban food systems to that of UK food security - but that is not to say that the thesis is broad and generalised. Instead, the thesis should be viewed as wide-reaching but specific in its goals. The aims of the thesis are clear; to understand the technical difficulties of integrating technical food systems within existing buildings above ground-level, to understand the impact naturally-lit building integrated technical food systems within high-density cities may have on UK food security and the mitigation of ecological damage, and to identify and discuss the social and economic benefits brought about by the integration of technical food systems within inner urban areas. For these goals to remain specific throughout the thesis, it is of critical importance to identify the scope and limitations of the research from the outset by stating what the thesis does and does not include. The prominent limitations of the thesis are noted below to give a better understanding of what is to be researched and what is to be left out at this stage. That is not to say that the items noted below are seen as inferior research tracks, but instead, as separate issues that do not form the critical path of knowledge acquisition relating to the systematic inquiries that are posed this thesis.

Soil-based food systems

The thesis focuses on building integrated technical food systems - i.e. soilless systems - and does not aim to further the understanding of soil-based agriculture within cities. This is due to issues relating to urban soil contamination, which will be discussed later, and the weight of soil-based systems which make them unlikely to exist within or upon buildings. This extends to peri-urban agriculture - i.e. farming on the fringes of cities - which primarily utilises soil-based systems to grow food. Although peri-urban agriculture is, and will continue to be, a vital method of food production, it is not included within the scope of the thesis.

Ground-based technical food systems

The thesis does not aim to further the knowledge of ground-based technical food systems within existing buildings. There are instances of these systems already in existence and although the knowledge relating to them is poorly communicated, if communicated at all, they exist as examples of urban food production nonetheless. Hence, the need to replicate or further understand these systems at this stage is not viewed as part of the critical path to improve the broader comprehension of urban agriculture as a whole, due to their inability to maximise the productivity of a single building. The scope of the thesis is to explore the integration of technical food systems above ground-level and upon the roof and facades of existing building because this is identified as an area of the built environment which is currently under-utilised for urban agriculture. It should be noted that the thesis understands the importance of ground-based food systems and their contribution to the current model of urban farming within high-density cities.

Technical food system knowledge

Although the basis of the thesis relates to the integration of technical food systems, it is not the role of the thesis to fill any knowledge gaps in technical food systems per se; such as the experimental filtration of fish sludge within aquaponic systems for the delivery of additional nutrients for example. Therefore, the thesis will utilise current and available knowledge relating to the construction of technical food systems to

better address the knowledge gaps relating to building integrated technical food systems above ground-level.

Target market and business model for urban food production

The thesis does not aim to address who the food should be grown for; i.e. those with the means to purchase expensive foods or those who struggle to afford five portions of fruit and veg each day. The thesis also does not aim to address the lack of any comprehensive large-scale business models for urban agriculture within high-density cities at this point in time. This is due to the economic complexity of such an undertaking, which in itself could be a three-year research project that would require a level of understanding of urban food production economics that does not exist at this moment in time. The development of a large-scale economic and business strategy for urban agriculture is significant to the future progression of the practice, and this will hopefully manifest in the future through continued and detailed research.

Further barriers to integration

In addition to the technical barriers that face the large-scale integration of technical food systems within high-density cities, there are also social and economic barriers that need to be considered. These considerations include such questions as ‘who will pay for these future food systems?’, ‘will building owners be open to the prospects of food production within or upon their buildings?’, and ‘what are the views of the general public towards urban agriculture and its place within future cities?’. Although these considerations are critical to the future understanding of the practice, and to any large-scale integration of the practice, they are also dependent, in one way or another, upon the successful integration of urban agricultural systems within existing buildings in high-density cities. As such, the technical challenges of integration are viewed as part of the critical path of understanding and knowledge acquisition within this thesis, with these additional barriers considered as ‘future work’.

3.5 - Research methodology

The purpose of this chapter is to identify the scope and the limitations of the thesis along with the methods by which knowledge will be captured and communicated. However, to enable conclusions to be drawn relating to the methods of research to be utilised within the thesis, as well as their validity within architectural research, the position of architectural research within the broader spectrum of academia - across subject and epistemological boundaries - must first be understood. It should be noted that although different research ideologies will be discussed, it is not the role of this chapter to determine which methods are 'better' than others, but rather to conclude which are the most applicable methods for the research questions presented within this thesis.

3.5.1 - The difficulties associated with design as research

The position of architectural research, and more so design as research, has long been discussed. Biggs and Buchler (2008, p.84) state that *"In Britain, and more widely in Europe, there is an ongoing debate about whether academic research in areas of design practice is different from the research that is developed in other disciplines"*. This is also concurred by Groat and Wang (2013, p21) who write *"over the past decade, there has been a particularly lively debate in architecture and allied fields about the extent in which "design" is or should be a template, or more broadly perhaps, a new "paradigm" for research in creative or professional domains"*. These authors, along with many others (Binder, et al., 2006, Rocco, 2009, Zimmerman, et al., 2010, Hauberg, 2011, de Queiroz Barbosa, et al., 2014,) are continually discussing the role of design within established research methods and its ability to acquire new knowledge and communicate it effectively.

There are differing points of view regarding the integration of design and research as a unified method of inquiry. Stephen Kieran describes research and design in a such a way that suggests they are different entities but at the same time complementary writing *"research brings science to our art"* (2007 p.31). In Kieran's opinion, the two cannot be separated within the discourse of architectural research. In contrast to this, Matthew Powers alludes to the differences between both design and research and questions the validity of their integration. Powers opinion is that integrating

design and research is unachievable due to each activity embodying different epistemological perspectives and set of values. In Powers own words any integration of design and research “*diminishes the most important aspects of each activity*” (2007, p.17). Powers personal objection towards the breaching of epistemological boundaries can, however, be contrasted by Groat and Wang who argue “*that both design and research can, and do, occur across a range of epistemological assumptions*” (2013 p. 24), stating that “*Design can be conducted within postpositivist understanding of knowledge (i.e., usually assumed to reflect the “scientific” method), and research can and does occur within “non-scientific” epistemologies, including what is often referred to as constructivist or subjectivist perspectives*”. Based on these points of view it can be seen that the discussion on the integration of design and research is still very much open and ongoing. As mentioned previously, it is the role of this chapter to acknowledge this ongoing debate in order to better determine the methods that should be utilised in answering the research questions posed within this thesis, and not to resolve the issues relating to the integration of design and research definitively.

The more specific debate relating to architectural design as research is succinctly discussed in the memorandum ‘What is Architectural Research?’ produced by the Royal Institute of British Architects (RIBA, 2005). Although the points raised within the memorandum offer no solutions relating to how architectural design can also contribute to research output, it does identify typical examples in which architecture struggles to integrate with established, and measurable forms of research. The charter granted to the RIBA in 1837 sets out the objectives of the institute as ‘*the advancement of architecture and the promotion of the acquirement of the knowledge of the various arts and sciences connected therewith*’ (RIBA, 2005, p.1). Hence, architecture within Britain is responsible for, and dependent on, the creation of new knowledge through research. Due to the nature of architecture - as a design-led practice - it can be viewed as different to traditional academic ideologies in which qualitative, quantitative or mixed methods are adopted to ascertain new knowledge. The danger within architectural design, in some case, is not the discovery of new knowledge but its comparative quantification thereafter. This, however, does not remove the responsibility of those involved with architectural research to interact with the rest of the academic community. Within their memorandum, the RIBA discuss what they describe as the ‘three myths’ of architectural research; these

being that ‘architecture is just architecture’, ‘architecture is not architecture’ and ‘building a building is research’, which are discussed individually in the following pages.

‘Architecture is just architecture’

The first myth, stating that ‘architecture is just architecture’, is written in response to the greater debate relating to architectural research and its ability to influence or reinforce research within other disciplines. This myth describes the situation where the decision is made by the author of the architectural research to separate themselves from the academic community and research in their own way; which is not recognisable within established research paradigms. Ultimately, this decision brings about two main issues; the first being that the research that is generated becomes difficult to transfer between different subject areas, such as the sciences, social sciences and humanities, and secondly, that the research may not be transferable between one source of architectural research and another. Therefore, this myth addresses ideas relating to ‘generalisation’ and ‘transferability’, in which results and knowledge can be applied to cases or situations beyond that of the original study (Collins, et al., 2003). Although the scale of applicability of the research does not need to be extensive, it must exist at some level in order for others to test the knowledge created and to assess the impact of the research within similar or varying contexts. If, for any reason, the research is not able to be generalised in any way it becomes very difficult to determine the originality, significance, and rigour of the research, even within a single architectural school, when measured against the Research Excellence Framework (2012).

This issue is discussed by Biggs and Buchler in their book ‘Architectural Research Methods: Second Edition’ who believe it is advantageous to have equal conditions between disciplines, which they describe as the “*situated position*” (2008, p.3); the antithesis of this being the ‘isolationist position’, which the RIBA addresses within this myth. They also discuss the need for balanced committees and audiences when awarding research degrees or judging fairly the quality of research produced. For example, the award of an arts-based research degree should be argued by a balanced committee comprised of engineers, psychologists and scientists, and not entirely by creative disciplines. They also note that audiences both generate and

consume any research that is generated and, therefore, this gives them the authority to decide whether questions, answers and methods are relevant, appropriate or meaningful (Biggs, et al., 2008).

Ultimately, architectural research needs to be transferable between other disciplines as well as other forms of architectural research, in order to not only better determine its originality, significance, and rigour, but also to improve the prospects of influencing, reinforcing and generating new knowledge across a wide spectrum of inquiry. In order to achieve this, architectural research must be able to discuss research methods in an explicit manner that is understood across a wide range of disciplines. This can include such terminology as to whether a research approach is 'etic' or 'emic' at an epistemological level, or whether the data captured is quantitative or qualitative, as well as including the scope and limitations of the research as a whole. Through this approach, architectural research can develop new methods of inquiry that are simultaneously fit for purpose as well as understood by the wider academic community.

'Architecture is not architecture'

The second myth described by the RIBA is that 'architecture is not architecture'. This discussion epitomises the multifaceted nature of architectural inquiry and the collections of subject areas that constitute it; from the arts to the sciences and everything in between. As a result of these many different focuses, architectural research has in the past dissected itself into its constituent parts, where each 'part' is subjected to the ideologies and methods of its respective discipline. Unlike the first myth, this approach improves the transferability of architectural research amongst other disciplines and allows knowledge to integrate and reinforce research within other fields. However, the lack of continuity between architectural research as a whole, again, makes it difficult to compare one source of architectural research to another and to determine the originality, significance, and rigour of the research. As a result of this approach, architectural research is unable to define its own methods, ideologies and goals, and in doing so, "*forgets what it might be in itself*" (RIBA, 2005, p.2); leading to loss of identity, direction and authority within an academic context.

Ultimately, the field of architectural research needs to be able to decipher for itself what constitutes good research instead of turning to other disciplines for direction and validation. Architectural research needs to be confident and capable in developing its own methods of inquiry that are simultaneously fit for purpose and understandable across a large range of academia, whilst maximising transferability between itself and other disciplines in order to better address knowledge creation within a multifaceted discipline.

'Building a building is research.'

The third and final myth outlined by the RIBA is that 'building a building is research'. Within this argument, the RIBA compare the construction of buildings against Bruce Archer's definition of research, which is "*systematic inquiry whose goal is communicable knowledge*" (1995, p.6). The RIBA describes the usual discourse of this presumed method of research as follows (2005, p.2);

1. "*Architectural knowledge ultimately resides in the built object*".
2. "*Every building by definition is unique and therefore original*".
3. "*The production of buildings can thus be defined as the production of new knowledge*".

However, when compared with Archers definition, which is reinforced by Kazys Varnelis' definition "*systematic research that produces a contribution to knowledge*" (2007, p.13) and James Snyder's definition "*systematic inquiry directed towards the creation of knowledge*" (1984, p.2), there are obvious conflicts between the construction of buildings and the creation of knowledge. The most prevalent issue relating to this misunderstanding is that a 'good building' may generate poor research and by contrast, a 'bad building' may generate good research. Therefore, the construction of a 'good' or 'bad' building cannot be used as a valid method of critique when determining whether novel, significant, or rigorous research has been produced. In addition to this, even if new knowledge has been produced, architects "*very rarely explicitly communicate [this] knowledge*" (2005, p.3); therefore, failing the second deliverable of research.

Although the construction of a building can, in some instances, fail as an acceptable method of architectural research - when compared to known definitions such as that of Bruce Archer - it can also be a valid method of architectural inquiry when conducted correctly. Ultimately, architecture research is a response to the built form and, therefore, the construction and occupation of buildings plays a key role in the development and progression of architectural knowledge. Whilst this may seem somewhat contradictory, it should be noted that what is being discussed in this final myth is not the validity of building construction as a method of architectural inquiry, but instead the methods by which new knowledge is generated, captured and disseminated as a result of the construction of buildings, or the lack therefore. This myth simply states that this method of inquiry should uphold the core values of research, much like any other form of architectural inquiry. In order to do so, and to generate new knowledge, the inquiry of the research should be specific and systematic from the outset and should aim to disseminate the knowledge effectively once the research has been concluded amongst researchers and practitioners alike, to further the development of architecture understanding as a whole.

The three 'myths' conclusion

The 'myths' noted in the preceding pages summarise the difficulties faced when the goal of architectural design is to deliver new knowledge through research. The discourse of architecture has in the past isolated itself from known forms of research, dissected itself to align with other forms of research and simply become complacent as it tries to appropriate the built form as research. However, these are simply lessons to be learned and do not suggest that architectural design and research cannot coexist. There are obvious differences between the practices of design and research, but that is not to say that the two cannot exist in the same space and at the same time compliment one another. Based on the points made it can be seen that in order for the architectural design to produce good quality research, the aims of the research need to be definitive and clear from the outset, the methods utilised within the research need to be explicit and understandable by a wide audience - not simply an architectural audience - and the knowledge created needs to be both communicable and transferable - even at a small scale - in order to determine the originality, significance and rigour of the research both within schools of architecture and by the wider academic community. However, for this to occur

efficiently within this thesis, it is important to understand the differences between design and research in order to better determine the ways in which they may coexist to achieve the research goals identified from the outset.

3.5.2 - Understanding design and research

When trying to understand the role of design within research it is fundamental to understand how design and research differ to enable deductions to be made as to how they may coexist within this, or any other, thesis. When analysing the definitions separately, through the views of others, they appear to exist at opposite ends of the spectrum, especially when considering the words of John Baldacchino (Baldacchino cited in Sullivan, 2009) who discusses that arts research should not concern itself with “*the search for stuff or facts*” but instead should aim to “*generate it*” (p.57). Taking Baldacchino’s somewhat reductionist view on research and design, it can be deduced that he views traditional research as the observation of ‘things’ within the present or past whereas design exists as a medium to predict the future of how something might be or can be. This view is also expressed by Herbert Simon (1999) who discusses that designers develop courses of action that aim to change things from how they are now, into preferred realities. Both see design and traditional research as two separate entities with opposite objectives. Although the above views seem logical, they identify the possibility of a dichotomous endeavour whereby the ‘search for stuff’ is achieved by ‘generating stuff’. Within the discipline of design, the impetus for any research is commonly referred to as ‘the problem’. This ‘problem’ prompts design development, which leads to the production or construction of the required artefact that meets the needs of the project or user. Within traditional research, the impetus for systematic inquiry is not a ‘problem’ to be solved, but more so a ‘question’ to be answered. The differences between the contribution, dominant process, temporal focus and impetus of design and research are summarised in table 3.1.

Table 3.1 - Matrix of the primary differences between design and research
(Groat, et al., 2013)

Facets of Difference	Design	Research
Contribution	Proposal for an artifact (from small-scale to large-scale interventions)	Knowledge and/or application that is generalizable (in diverse epistemological terms)
Dominant Processes	Generative	Analytical and systematic
Temporal Focus	Future	Past and/or present
Impetus	Problem	Question

To consider these differences further, ‘research’ and ‘design’ will be discussed individually as different methods of inquiry in the following sections, to enable conclusions to be made relating to how they may coexist within this thesis, in order to better address the aims and objectives of the research questions.

3.5.3 - What is research?

Research, as defined by Graeme Sullivan is “*the search for stuff*” (2005, p.57). In the context of established research methods, ‘stuff’ can either be a ‘thing’, a ‘working principle’ or an observed ‘result’. To rephrase the definition posed by Archer (1995, p.6) - that research is the “*systematic inquiry whose goal is communicable knowledge*” - using the keywords within the description such as ‘systematic’, ‘inquiry’, ‘goal’, ‘knowledge’, and ‘communicable’, his definition can be extrapolated to become; a plan which is devised to find answers to questions relating to specific actions or tasks, which enables the creation of new knowledge as opposed to purely information, based on a framework of understanding that allows the knowledge to be intelligible to an appropriate audience and communicated appropriately. This definition - backed up Snyder and Varnelis - is widely accepted as the definition of research.

Therefore, for design to be considered as research, it firstly needs to be systematic in some way. Although it is possible to acquire knowledge of the built environment simply by walking through a city and observing the buildings that one passes on a journey to work, for example, the notion of a systematic inquiry imposes rules upon the journey to help govern how knowledge is generated. This includes but is not limited to, the way in which the information is gathered and separated from the rest of the experiential qualities of the journey, how this information is categorised, how it is analysed, and how it is presented. Most importantly, the term 'systematic' does not only relate to the 'scientific method' - seen by many as the purest form of research - but also relates to, and is a necessary requirement of, all paradigms of research. Some critics of scientific research believe that although an experiment can be appropriate to the task, it can also be far too reductionist (Groat, et al. 2013). While it is true that designing a scientific experiment around precisely defined variables is reductionist, it is also true within architectural research that the coding or categorising of interview responses, or case studies, for example, is also reductionist. Ultimately, research has to be reductionist because it is necessary to reduce the data acquired through experience, experiment and research programme into smaller chunks of information that allow others to consume and interpret the research in an efficient manner. The primary difference, therefore, between a laboratory experiment and that of a qualitative study is simply the method of reduction that has been utilised to capture and communicate the knowledge effectively.

The knowledge created through systematic inquiry can exist upon a spectrum of applicability that can be described as big, middle-range and small (Moore, 1997). An example of 'big' research would be Einstein's theory of General Relativity, which can explain a large scope of reality, or the discovery of gravity, which explains both the movement of celestial bodies and the drop of a coin. At the 'small' end of the scale would be very localised research that has no larger application such as how the weather makes a specific people feel. Within the 'middle range' can be found knowledge that neither has a large scope nor small scope of applicability. This knowledge has applicability within a specific discipline but is typically unable to contribute any knowledge or meaning to other disciplines. Research, therefore, can describe an array of different situations whereby systematic inquiry is utilised to generate new knowledge that is communicated efficiently; regardless of context or

scale of applicability. Architectural research is unlikely to be found at the 'big' scale of applicability; however, it is very likely to exist at the 'middle-range' and 'small' scales of applicability. Whether the knowledge generated refers to new fire safety regulations for all newly constructed office buildings or simply a new glass to glass connection for an external glazing system, it can be seen that architectural design is inseparable from the creation of knowledge through research.

3.5.4 - What is design?

In the past, many scholars, researchers and practitioners have proposed a wide range of definitions for the 'nature' of design. Two of the more well-known academics on this subject are Donald Schön and Herbert Simon. Herbert Simon (1996, p.111) defines the nature of design as "*courses of action aimed at changing existing situations into preferred ones*". Donald Schön, however, believes this definition is too focused on active problem solving and optimisation instead of reflective practice. Schön believes that reflective practice - and therefore, design - exists in all professions, preferring John Dewy's view that a designer is someone who "*converts indeterminate situations to determinate ones*" (Schön, 1987, p.42). More specifically, Schön believes the role of design professionals within the built environment, such as an architect, landscape designer or interior designer is to produce an image - or representation - of something that is to be made, which has physical form and occupies space within reality. Thirty years on, scholars such as Nigel Cross are still reinterpreting the sentiments of Schön stating that "*the most essential thing that any designer does is to provide, for those who will make the new artefact, a description of what that artefact should be like*" (Cross, 2006, pp.15-16).

Whether it is considered a description or a representation of what may occupy tangible space in the near future, the process of design looks to the future as a generative discipline, utilising reflective practice and logical reasoning either to find a solution to a specific problem or more generally to generate 'stuff'. Ultimately, designers view the world in a different way to that of particle physicists, for example, but the differences between design and research are not as stark as they may first seem due to the logical reasoning exemplified in both fields of inquiry.

3.5.5 - Inductive, deductive and abductive reasoning

A logical argument is comprised of three concise elements; a 'thing'; whether it be a building or planet; a 'working principle' such as how people evacuate a building or gravity; or an aspired 'value' or observed 'result' such as decreasing the evacuation time of a building or the position of a planet in the universe due to the forces acting upon it. These elements constitute the following equation.

$$\text{(WHAT)} + \text{(HOW)} = \text{(RESULT)}$$

Within research, one of three methods of logical reasoning will be utilised when approaching a 'question' or a 'problem', in which one or more of these entities is unknown. The unknown value is either the answer to the question or the solution to the problem, and it is within this unknown value that knowledge is discovered, generated and captured. The three different methods of knowledge discovery will be discussed below to identify the similarities and differences between design and research.

Deduction

Within deductive reasoning the 'what' is known and the 'how' is known but the 'result' is unknown.

$$\text{(WHAT)} + \text{(HOW)} = \text{(??????)}$$

For instance, if it is known that there is a comet in the sky, and the natural laws that govern its movement are known, it can be predicted where the comet will be at a certain point in time. Deductive reasoning is, therefore, a way in which the world can be predicted.

Induction

Inductive reasoning is employed when the what - i.e. the comet - is known, and the result - i.e. the comet's position over time - is known, but the principles governing its movement are unknown.

$$\text{(WHAT)} + \text{(??????)} = \text{(RESULT)}$$

This form of logical reasoning is core to the principles of scientific discovery because it leads to the creation of hypotheses, which underpin scientific inquiry. These hypotheses are then subjected to experimentation, which is driven by deduction, with an aim to falsify the claims made regarding, in this example, the principles governing the movement of the comet. Any experiment used to disprove the hypothesis is a deductive process because the object has had the proposed hypothesis applied to it to confirm whether what is observed in the experiment is the same as what is observed in reality.

As a result, it can be seen that inductive reasoning informs 'discovery' while 'deductive' reasoning informs 'justification'. These two forms of reasoning allow a prediction to be made or a phenomenon to be explained. However, in some cases, inductive hypothesis generation is insufficient, and abductive reasoning is required.

Abduction

Abductive thinking - unlike inductive and deductive thinking, which are typical drivers for scientific discovery and justification - is the logical reasoning used during the process of 'creation'; i.e. it is the 'what' or the 'artefact' that is unknown. However, within a design-based context, the equation changes slightly with the 'result' becoming a desired or aspired 'value'.

$$\text{(??????)} + \text{(HOW)} = \text{(VALUE)}$$

Abduction, unlike deduction and induction, exists in two forms. The first form of abductive reasoning is seen above; where the object within the research - or the 'what' - is unknown. This is associated with conventional problem-solving. For

example, if a staircase is required to carry people from the ground floor of a building to the first floor of a building, then a design for a stair is required. The aspiration for the design - or the 'value' - is that the stair successfully allows people to move from the ground floor to the first floor and vice versa, whereas the 'how' is the working principles that govern the design of the stair such as how long a flight of stairs can be before a landing is required, or how steep a stair can be. At the beginning of the process, the final design of the stair - i.e. the 'what' - is unknown but the working principles and the desired value help drive the design and process and ultimately derive a design. This is considered a form of 'closed' problem solving and is something that humans do without knowing on a daily basis.

In the second form of abductive reasoning, it is only the desired 'value' that is known. This makes it far more complex than the other types of logical reasoning and is closely associated with conceptual design. This is known as an 'open' form of reasoning.

$$(??????) + (??????) = (\text{VALUE})$$

The challenge therefore in this second form of abductive thinking is to simultaneously design an object that provides a solution to the problem while designing a working principle upon which the design is derived. The need to deliver two unknowns within a three-part equation leads to design practices that are very different to conventional problem-solving.

Abductive reasoning, although highly characteristic of design "*is not unique to design. In both science and technology, and in daily life, abductive steps are taken in the search for new ideas*" (Roozenburg, 1993, p.17) and is seen as "*essential to hypothesis generation in science*" (March, 1984, p.269). Some of the biggest scientific discoveries of the 21st century have relied upon abductive hypotheses to generate knowledge. One of the most notable examples in recent years was the discovery of the Higgs boson particle - otherwise known as the 'god particle', which is believed to give mass to the universe. The Higgs boson particle was first hypothesised in the 1960's by Peter Higgs and was estimated to have an average lifespan of 1.56×10^{-22} seconds (Cabbolet, 2015). In 2012 the Higgs boson particle was discovered, but the theory of its existence was dependent upon abductive

reasoning, due to the unknown existence of the particle and the unknown forces that govern its creation, movement and decay.

Ultimately, abductive reasoning is seen to be the only *“logical operation which introduces new ideas; for induction does nothing but determine a value; and deduction merely evolves the consequences of a pure hypothesis”* (March, 1984, p.269); or in summary, abduction creates, deduction predicts, and induction evaluates. Research that seeks to explain complex phenomena may not always be able to rely on long-standing research methods to address the questions or problems of interest, and new methods must be designed when approaching a novel project. Similarly, the process of design very rarely rests upon well-established methods of development, due to varying contexts and the possibility of unlimited design options. As a result, the process of design is continually inventing new ways of designing to arrive at and determine applicable artefacts that resolve the problem or issue in question. Although, this form of open reasoning exists in both the generation of complex scientific hypotheses and the development of design solutions, the way in which both design and more established research tracts view the world is very different.

3.5.6 - The different paradigms of research

There are several challenges when proposing a framework of inquiry for the full scope of architectural design and research. This is primarily due to the exceedingly multidisciplinary nature of architecture - as both a discipline and as a profession - which ranges from the historical research of building styles and designs all the way through to the technical research of heat loss of building elements. This multifaceted approach to architectural research, and the many different foci of interest, ultimately restricts architectural research from existing as a single form of inquiry. Architectural research as a collective, therefore, utilises all systems of inquiry - otherwise known as research paradigms - to successfully answer the question or resolve the problem that generated the aims of the research. Research paradigms encapsulate the school of thought, strategy and tactics that are typically used in generalised areas of research, and offer the opportunity for research designs - i.e. the design of method - to be compared with one another to justify the use of one method in comparison to another. These paradigms exist upon a spectrum - or continuum - that range from

objective to subjective inquiry and encapsulates postpositivist research methods, intersubjective research methods and constructivist research methods (Groat, et al., 2013). These three paradigms are the result of ontological assumptions, epistemological beliefs and methodological conclusions.

Postpositivism

At the objective end of the spectrum is postpositivism, which assumes that reality can be objectively measured and described through quantitative data capture. The ontological position of postpositivism is that there is a single reality that can be known to a certain level of probability through objective inquiry. Positivism - the precursor to postpositivism - believed that there is a single reality that can be known without doubt through objective inquiry. The difference between positivism and postpositivism is that once an idea was proven through a positivist paradigm, it was seen to be an absolute truth, whereas the proof of an idea through the use of postpositivism is known only to be true until it is disproven. Postpositivism allows others to recreate an experiment, for example, and see if they find the same results. Positivism was considered to be a naive belief system because it does not allow an idea or belief to evolve. Instead, the idea or belief is simply known to be correct (Mertens, 2010). Positivism assumed that objectivity could be wholly achieved through a research process whereas postpositivism understands that objectivity is the goal of the research process, but it might not be perfectly realised.

In addition to the ontological assumptions of postpositivism are the complementary beliefs that the values outside of the inquiry should remain as such, or at the very least be controlled. That is to say that the researcher should remain separate from the experiment being conducted. The epistemological belief of postpositivists allows the cause and the effect to be observed and the discovery of knowledge to occur in the most objective way possible. In the context of architectural research, the postpositivist paradigm would most readily relate to the technical domains of the discipline, such as energy conservation or the strength of a new material. Within these topics is a shared belief that that world can be objectively measured or at the very least can be assumed to reflect reality as closely as possible.

Intersubjectivism

In between postpositivism and constructivism is the 'intersubject' region. This region of the spectrum of research paradigms is referred to as such, by Groat and Wang (2013), due to the lack of a widely accepted label for this interstitial zone between objectivity and subjectivity. This 'intersubjective' region, therefore, recognises the multiplicity of this zone along with the need for socially shared action and knowledge. The ontological position of intersubjectivity acknowledges that there are many diverse viewpoints of reality, which together can achieve a shared understanding. In contrast to postpositivism, intersubjectivity believes that is neither possible nor necessary for research to exist objectively. Instead, intersubjectivity recognises the importance of values and meaning in framing the aims of the research and in analysing and interpreting the results (Teddlie, et al., 2009), because causality is seen as only one of many relationships or interactions in the study. Within the remit of architectural research, this approach is typically utilised when assessing people's actions such as how those working within a hospital interpret interconnected spaces, or how a design team functions during a bid for a large architectural project. Intersubjectivity, therefore, sits in the middle ground between objectivity and subjectivity and aims to understand a collective experience through the viewpoints of multiple actors.

Constructivism

At the opposite end of the spectrum to postpositivism is constructivism. Many scholars and authors have come to adopt the term 'constructivist' as a replacement for several other terms such as 'naturalistic', 'qualitative' and 'interpretive' (Creswell, et al., 2009; Denzin, et al., 2008; Mertens, 2010; Teddlie, et al., 2009), which have in the past been used to explain the same paradigm of research. Denzin and Lincoln believe the ontological position of constructivism is 'relativist' (Denzin, et al., 2008, p. 32) whereby multiple viewpoints infer multiple realities, which are understood as being socially constructed.

The constructivist paradigm aims to achieve an in-depth insight or interpretation of a given context from the vantage point of the actors within it, who experience and find meaning in different ways. Within an architectural context, this approach typically

takes the form of an in-depth analysis of questionnaires or interviews, which strives to gain a greater understanding of the influence of architectural design on individual people. Ultimately, the constructivist paradigm believes there is an infinite number of realities, due to the multiple combinations of researcher, researchers, study groups, and people, and that as a consequence knowledge is only temporary because it is subject to reinterpretation.

Categories of data

The final area of differentiation with regards to research paradigms is the category of data collected. This refers to the nature of data as either 'quantitative' - i.e. measurable - or 'qualitative' - i.e. experiential. Arcing back to the definitions of postpositivism, intersubjectivism and constructivism it can be concluded that quantitative data is typically associated with an objective view of reality - i.e. postpositivism - and that experiential data is typically associated with a subjective view of reality - i.e. constructivist. Although it is unlikely that qualitative data would be utilised within the postpositivist paradigm due to the contradiction it poses to the belief of a single reality, it is possible that both quantitative and qualitative data can exist simultaneously within both subjectivist and constructivist paradigms.

Summary of Research Paradigms

From the descriptions provided of postpositivism, intersubjectivism and constructivism it is apparent that architectural research cannot be restricted to one of these three research paradigms. In some instances, architectural research needs to be produced objectively when collecting quantitative data and in other cases, the research needs to be produced subjectively when interpreting how individuals interpret the environment they inhabit. Architecture, much like the sciences, can utilise any of the three research paradigms to provide meaningful answers to the research objectives posed; it is simply a case of identifying which method of inquiry is best suited to the task at hand. The different epistemological and ontological assumptions of the three distinct research paradigms are summarised in table 3.2.

Table 3.2 - Continuum of research paradigms (Groat, et al., 2013)

	Objective < —————> Subjective				
	Positivism/Postpositivism		Intersubjective	Constructivism	
Epistemology	Knower distinct from object of inquiry	Knowing through distance from object	Knowledge framed by understanding sociocultural engagement	Knowledge co-constructed with participants	Knowledge perpetually provisional
Ontology	Assumes objective reality	External reality revealed probabilistically	Diverse realities situated in sociocultural context	Multiple constructed realities	Infinite realities

3.5.7 - Research by design

Based on the preceding pages it can be concluded that both research and design are indeed different methods of inquiry. However, the nature of ‘creation’ is something that exists across multiple disciplines; not simply in design-based practices. As a result, abductive thinking and open reasoning are utilised to determine ‘the unknown’, whether this involves the creation of a new architectural project or the possible existence of an unknown particle in the universe. Based on the definitions of research presented in this chapter, for design to be considered as research it must be both systematic in its aims and efficiently communicated thereafter. However, taking into consideration the views of John Baldacchino and Herbert Simon, design within research must also be generative and propositional; i.e. with a focus on how things could be in the future. This is considered to be the key difference between design and traditional research and is something that is an essential component of a method of design inquiry referred to as ‘research by design’.

Research by design is a modern term, which is used to describe a method of rigorous inquiry that utilises design as a vehicle to discover new knowledge. The genesis of this method of inquiry can be traced back to the early 1920’s and the perceived need to ‘scientise design’ as a process by which architectural design could become objective and rational (Cross, 2001). These aspirations resurfaced

again during the 1960's - which was referred to by Buckminster Fuller as the 'design science decade' (Baldwin, 1996) - with the 'Conference of Design Methods' in 1962, which marked the launch of design methodology as a field of inquiry; again, with a strong desire to rationalise and objectify the design process (Jones, et al., 1963). During the 1980's, however, there was a strong feeling that design research had to move on from simplistic comparisons and distinctions between design and science. This resulted in a general belief that science may not be able to contribute to the process of design as some had first thought, due to the different nature of design and science; i.e. that science aims to identify the components of existing structures, whereas design aims to shape the components of new structures (Alexander, 1964). Ultimately, the positivist paradigm associated with scientific research focused on solving well-formed problems, whereas constructivist paradigms more closely related to design practice had to deal with 'messy' and problematic situations (Schön, 1983); otherwise referred to as 'wicked problems' that are fundamentally un-amenable to the methods presented by science (Rittel, et al., 1973).

Today, research by design is defined as a method of inquiry that aims to utilise design as a process of both exploration and investigation through the development of a project and the different visual methods utilised to communicate its meaning, such as sketches and drawings (de Queiroz Barbosa, et al., 2014). Research by design, therefore, explains the ways in which research and design are interconnected and utilised as a pathway through which new insights, knowledge, practices or products come into being (Hauberg, 2011, Roggema, 2016). There are two major arguments for the use of research by design within design research. These include the need to plan for a future that can no longer be predicted with certainty, as well as the nature of many environmental, social and economic issues that have no 'final solution'; i.e. there a multitude of different approaches that may alleviate the problems encountered, and in most cases, these approaches cannot be quantified or validated. The design solution is therefore described as the optimum solution for the current situation, rather than the 'answer' or the 'truth' (Binder, et al., 2006).

Due to the nature of problem-solving associated with any design process - i.e. that of an iterative process - the method of inquiry associated with research by design needs to be reflexive in order to better represent the process of design (Beck, 1994).

This typically involves defining the goals of the research and the key criteria of the proposal, developing a design proposal which best addresses the problem or issue, before rationalising the proposal, both theoretically and practically where possible, to determine its viability as a considered and effective solution. The conclusion of the rationalisation may be that the proposed design is not as suitable as first through, in which case what is learnt through the design process is plugged back into the first stage so the process can start again. This can occur multiple times until the proposal passes the rationalisation stage, at which point, the findings can be communicated (Roggema, 2016). Ultimately, it is this reflexive process that leads to the creation of new and innovative knowledge within research by design.

Based on the information discussed, it can be concluded that research by design is an appropriate term to describe the broad method of investigation that will be required to best address the aims and objectives of this thesis. This is due to the nature of the challenges that the thesis aims to address - i.e. food security, ecological damage, job creation and health and wellbeing - which are the result of multiple interactions and forces that are constantly changing as time progresses; otherwise referred to as wicked problems. As a result of this, these issues can be improved or resolved through the implementation of multiple design solutions, which individually define an optimal solution for the future based on the current situation and the forces in play; reflecting the temporal focus of the research, which focuses on the future impacts of building integrated technical food systems. Additionally, the research questions posed within this thesis cannot be answered effectively through the use of established scientific or technical methods of inquiry, due to the lack of accessible knowledge relating the building integrated technical food systems, which further reinforces the problems addressed within this thesis as 'wicked' (Zimmerman, et al., 2010). The delivery of a working technical food system will ultimately be determined by its context - i.e. 'the building' - and the process of delivering such a system can only be iterative due to a multitude of 'unknowns' that will arise throughout the process of the design of the technical food system. The knowledge discovered as part of this iterative process can then be extrapolated to understand the productivity of cities as a result of naturally-lit building integrated technical food systems and the potential benefits they may provide to urban population in the future.

3.6 - The methods of research used within the thesis

As a result of the information contained in this chapter - i.e. the previous pitfalls of architectural research, the differences and similarities of design and research, the scales of applicability, abductive, deductive and inductive reasoning, the different research paradigms, the different categories of collected data and the characteristics of research by design - it can be concluded that any research project associated with both architecture and design should include the following attributes in order to effectively communicate the research, the methods utilised, and the knowledge generated, to architectural audiences and the wider academic community.

- The research inquiry needs to be propositional and systematic from the outset with clear and understandable goals, including the scope and limitations of the research, with a focus on planning an unknown future.
- The methods utilised need to be explicit, clear and understandable by a wider academic audience through the use of recognisable terminologies, such as the ontological position of the research, the epistemological position of the research, the expected scale of applicability and the category and description of data to be collected.
- The methods utilised within the study should also clearly state the tactics that will be employed to efficiently investigate, analyse and synthesise the knowledge related to the research question.
- The process utilised in the design element of the study should be reflexive and the solution or solutions generated should strike a balance between multiple forces and factors, with a focus on delivering optimal solutions for the present situation.
- The research, analysis and knowledge contained within the study needs to be disseminated and communicated effectively afterwards, with a view to being transferable and generalisable between other forms of architectural research and other disciplines not necessarily associated with architecture.

In order to adhere to these characteristics it can be stated that the nature of this thesis is indeed propositional and that the aims and objectives of the thesis are clearly stated at the beginning of this chapter. However, the detailed methods related to each research question are still to be discussed. Although the term research by design identifies a method of design inquiry, which is applicable to this thesis, it is not felt that it sufficiently addresses all aspects of the research questions posed. Therefore, a more detailed description of the method that will be utilised to answer each research question will be required, which collectively fall under the umbrella term of research by design.

As discussed previously, architectural research covers a wide range of ontological and epistemological assumptions and, therefore, cannot be affiliated with a single method of knowledge acquisition. There are, however, six established and recognised methods of architectural inquiry that suit a broad spectrum of research goals. These established research methods are categorised as historical research, qualitative research, correlational research, experimental and quasi-experimental research, simulation research and logical argumentation (Groat, et al., 2013). It is not felt necessary to give a detailed description of each of these research methods in this chapter, due to the complexity of some of the methods that are not applicable to this thesis. Instead, the best-suited research method will be discussed in detail, and justified accordingly, when addressing each research question individually. The focus of this thesis is multifaceted and will, therefore, rely on a range of different methods of inquiry to best address the research questions posed. The three research questions will now be reiterated along with a detailed description of the chosen research method for each research question, which will include information relating to the ontological position of the method, the epistemological position of the method, the expected scale of applicability of the knowledge generated, and the category and description of data to be collected, along with the tactics to be used, which collectively form the method of inquiry.

3.6.1 - Research question one

What are the prominent technical challenges associated with integrating technical food systems within existing buildings above ground-level?

Paradigm	
Method to be used	<i>Quasi-experimentation</i>
Ontological position	<i>Subjective</i>
Epistemological position	<i>Emic (interactive)</i>
Scale of applicability	Mid-range
Data collected	Qualitative and quantitative

Tactics	
Study	The integration of a technical food system within an existing building.
Setting	Field Study.
Treatment	Design, construction and commissioning of a technical food system within an existing building.
Observations	The technical difficulties encountered.

The premise of research question one is that there is simply not enough communicable knowledge currently available to determine how ‘easy’ or ‘difficult’ it is to integrate technical food systems within existing buildings, and more specifically, to determine the technical challenges that face the integration of such systems. It is, therefore, very difficult to conclude, at this moment in time, whether building integrated technical food systems are a feasible solution to improving domestic food security or not. Due to the lack of knowledge relating to this, it is imperative that a technical food system is designed, constructed and commissioned within an existing building to better understand, identify and discuss the technical challenges that face

its integration. As previously mentioned, there are knowledge gaps relating to both ground-level and above-ground-level technical food systems that are integrated within or upon existing buildings. However, due to the potential increase in productivity as a result of technical food system upon multiple floor plates - as opposed to a single food system at ground-level - the thesis will focus on the design and construction of an above ground-level technical food system; i.e. a technical food system that is placed upon an intermediate floor plate, as opposed to the ground floor plate.

This ambitious approach is required in order to answer research question one because there is no other way of accessing, re-appropriating or discovering this knowledge through any other means. Ultimately, this method will utilise a reflexive research by design approach in which the design of the technical food system will be designed and rationalised multiple times - due to the unknown technical difficulties associated with integrating such systems within existing building - until an optimal solution is found, which best addresses the current situation. The construction of this optimal solution, however, will utilise a research by practice approach - more commonly known as 'practice-based research' - due to its construction in the real world, or as a result of 'practice'. Practice-based Research is an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice (Candy, 2006). The construction of a functioning technical food systems within an existing building will consequently manifest as a result of a 'research by design by practice' approach.

The detailed method associated with research question one is, therefore, best described as 'experimentation'. The defining characteristics of an experiment are the use of a treatment or variable with a clear unit of assignment, the measurement of the effects of the treatment or variable - i.e. the results - the use of a control group and the focus on causality (Standish, et al., 2002). Although this definition is true for quantitative experimentation, it does not address the nuances of qualitative experimentation; where the role of 'cause and 'effect' are replaced, in this instance, with 'treatment' and 'observation'.

Due to the use of an existing building - within which the technical food system will be designed and built - the experiment will be classed as 'field' research, which

describes the context of the research as outside of a controlled laboratory setting. More specifically, the experiment should be considered as 'design-decision research' - which is an abstraction of the more commonly used phrase 'action research'. Action research describes studies which examine contextual situations with an emphasis on contextual knowledge as opposed to generalisable knowledge; i.e. the researcher is outside of the situation or context being observed. Design-decision research on the other hand - proposed by Farbstein and Kantrowitz in 1991 - identifies the position of the researcher as embedded within the overall process. Farbstein and Kantrowitz identify that within a design-decision research method the researchers and the designers become a single community, which is very fitting for this thesis because the author will act as both researcher and designer, along with other designers that collectively form the 'design team'.

Due to the inescapable fact that an existing building is required in order to conduct the research, the chosen method for research question one is more appropriately referred to as 'quasi-experimental' instead of simply 'experimental'. This important distinction determines the way in which the units of assignment are selected. In experimental research, the aim is to achieve comparability between the units of treatment through random assignment. Random assignment allows the researcher to remain as detached as possible from the research, which improves the objective nature of the knowledge created. The use of the term 'quasi-experimental' identifies that the units of assignment are non-random and less objective. This term is typically given to field research where the context or people cannot be randomly assigned due to ethical or practical reasons. As such the construction of a technical food system within an existing building can only exist within a single building that has to be identified and selected beforehand and is therefore not considered random.

In order to answer research question one in the most appropriate way possible, it is important that the method utilised is as explicit as explicit. As such, it is important to stress the following points. A key part of an experiment is to identify and measure the pretest scenario - also known as the control - and the posttest scenario in order to calculate the difference between the two. In the case of research question one, this will be achieved by stating that the existing building utilised was capable of growing no crops before the experiment and is be capable of growing 'x' number of crops after the experiment. Although the number of crops grown is not a metric that

is applicable to research question one, it will become a key metric for both research question two and research question three. Hence, the capture of this data is imperative to the completion of the research objectives set out in this thesis. It is also important to note that the experiment is to be considered as subjective due to the involvement of the author as both researcher and designer. If another researcher or designer was to lead the research it is highly likely that they would yield different outcomes due to their own experiential and heuristic views on research and design. The other members of the design team will also affect the outcomes of the research because they are, again, a product of their own experiential and heuristic views. Finally, the conclusions derived from the experiment will ultimately comprise of empirical qualitative data that explains the technical difficulties experienced during the integration of the technical food system. It is expected that the technical difficulties encountered will be key challenges that face the integration of other technical food systems above ground-level in other buildings in the future. Hence, the scale of applicability is considered to be mid-range.

To summarise; research question one will be answered through a detailed account of the design, construction and commissioning of a technical food system above ground-level within an existing building, which utilises a 'research by design by practice' approach. This will provide and document first-hand knowledge relating to the primary technical challenges that will face the integration of technical food systems within existing buildings above ground-level in the future. Although the issues encountered as part of this process will be specific to the building itself, it will nonetheless demonstrate whether the integration of technical food systems above ground-level within existing buildings is easy or complex. The publication of the design process, schematics, and final working technical food system within this thesis will allow others to critique the system, hopefully leading to adaptations and improvements, that will improve the integration of such systems in the future. Upon successful completion of this thesis, a book will also be produced that documents the design and construction of the building integrated technical food system and the findings from the research. It is absolutely critical that the information within the thesis is shared with others in order to further the understanding of building integrated technical food systems and to mitigate any complexities faced as a result of their integration in the future, in order to push the goals of urban agriculture forward.

3.6.2 - Research question two

What effect, if any, would the large-scale implementation of naturally-lit building integrated technical food systems within inner urban areas have on the food security of the United Kingdom, and how might food produced in this way help mitigate ecological damage?

Paradigm	
Method to be used	Simulation
Ontological position	Intersubjective
Epistemological position	Etic (detached)
Scale of applicability	Mid-range
Data collected	Quantitative

Tactic 1	
Study	The resulting combination of light capture analysis with food production metrics from the building integrated technical food systems to determine the productive capacity of a single city.
Setting	Computer simulation.
Treatment	Annual light capture upon the surfaces of a city as a result of daily and annual sun movement.
Observations	Light areas suitable for crop growth and dark areas unsuitable for crop growth across the chosen city.

Tactic 2	
Study	The estimated productive capacity of the UK, as a result of naturally-lit technical food systems and the effect this will have on UK food security and the mitigation of ecological damage.
Setting	Mathematical simulation.
Treatment	The relationship between geographical area of the chosen city and productive capacity of the chosen city, when applied to the collective inner urban area of the UK.
Observations	The amount of food UK cities could produce as a result of naturally-lit building integrated technical food systems within inner urban areas and the resulting decrease in pollution and the demand for foreign agricultural land.

Research question two will rely on simulation research to estimate the total productive capacity of UK cities as a result of the integration of naturally-lit building integrated technical food systems. Simulation studies allow knowledge relating to real-world conditions to be determined and collated without the constraints of ethical, practical or financial barriers (Groat, et al., 2013). Simulation research, therefore, aims to create a copy of reality with varying levels of detail and accuracy, depending on the best interests of the research question posed.

Simulation research is seen as an extension of experimental research because it relies on the same basic structures that govern experimentation, with the context changing to that of a representation of the real world rather than occurring in the real world. For example, if an atrium within a building design was a key component in the ventilation strategy of a new architectural project there are two primary methods in which its effectiveness could be proven. The building could be built and then the atrium tested - which could lead to major design changes and, as a result, increase build costs - or the building could be modelled within a three-dimensional design package and tested using fluid dynamics analysis; leading to design amendments before construction starts that could result in reduced build costs. In both instances,

the outcomes should be very similar but the costs incurred as a result of the two approaches would be very different. In this example, testing the atrium before it is constructed to determine its efficacy as part of the ventilation strategy stops the atrium being built incorrectly in the first instance and amended once built. Simulation research, therefore, offers a representation of the real-world without actually being there and extends well beyond architecture to other disciplines such as aviation and weather analysis.

Simulation research has some strengths and some weaknesses when compared with traditional experimentation. For example, experimentation is necessarily reductive in that it isolates variables from the rest of the world to better identify causal factors in the study. Simulation research, on the other hand, aims to replicate all the relevant variables within the context or phenomenon being studied. Simulation research is, therefore, capable of identifying multiple causal factors and effects simultaneously and, with the help of computers, is capable of collecting and storing multiple data streams for interpretation at a later date. Simulation studies can be as simple or as complex as required, but their success is dependent on how authentically the context of the experiment is replicated in the study (Groat, et al., 2013). This authenticity is determined by four key attributes; the accuracy of replication, the completeness of data input, the programmed spontaneity or randomness, and the usability. These key attributes can be considered as limitations to the success of simulation research if they are not identified and addressed before the research is conducted.

Due to the nature of simulation research - to replicate reality - there is potentially an infinite number of variables that could be used to create an accurate simulation. It is, therefore, important to identify the variables that have been utilised within the study and the variables that have not to give a complete picture of the simulation that has been used. With regards to the variables that have been used it is also important to state to what level of accuracy they have been replicated. For instance, and to use a previously used example, if simulation research was utilised as a research method to determine the speed at which people can evacuate a proposed building, it would be important to include objects that might interfere with the escape route such as chairs or tables. However, it is not necessary to include the full detail of the objects such as castors or number of legs. In this instance, a block representing the scale of

the object would suffice. Stating the level of accuracy utilised within the study allows the audience to better understand the methods that have been used and offers an opportunity for the methods to be adopted and improved by others in future research. Herbert Simon (1996) refers to this as 'satisficing' - a combination of 'satisfy' and 'suffice' - which is something in the inner environment - i.e. the simulation - that can fulfil its intended purpose or use in relation to the outer environment. It should be noted that there is a distinction to be made between a representation and a simulation. A representation is an entity - such as drawing, a photograph or a scale model - that describes a real object and has measurable qualities. However, these representations do not constitute a simulation until data from various scenarios are generated, at which point a simulation has taken place (Groat, et al., 2013).

The use of computer technology has further blurred the boundaries between representation and simulation in recent years. Software such as Google Sketchup or Autodesk Revit provides a platform into which many representations of the building can be taken - i.e. multiple perspective views or building plans. However, these are still representations of an architectural design until data is generated from them. This could include sun path scenarios or energy efficiency for example. Ultimately, it is the data generated from a representation of reality that constitutes a simulation, which could include anything from the inner workings of a nuclear reactor - that would require exceptional computational power - to how quickly a person can be freed from a crashed car in a controlled environment by the fire brigade. Simulation research is, therefore, a remarkably versatile and widely adopted research tool that can be applied to a broad range of scenarios and topics. In addition to this, simulation research can be partnered with other research methods to form combined strategies.

Typically, in mixed method research designs, a general principle will be identified within an experiment, which can then be extrapolated within a simulation study to estimate or forecast the results over a wider context or broader time period, for example. This is a widely accepted method of research because simulation research is seen as an extension of experimentation and is, therefore, commonly deployed in environmental technology research. An example of this is a study by Stazi, Mastrucci and di Perna (2012) in which the authors present an analysis of an

experimental solar wall - or Trombe wall - for residential buildings in a Mediterranean climate. The authors aim is to investigate how energy savings may be achieved in both winter and summer through experimental testing and subsequent simulation modelling. There were three treatments of the solar wall that were tested; a non-ventilated solar wall, a Trombe wall in the winter months with air circulating from the adjacent space through the cavity, and a Trombe wall in the summer months with the air circulating from the outside through the cavity and returning to the outside. These treatments were built into a facade prototype which was fitted to a residential building and tested for several years to determine how the different treatments of solar wall affected the thermal behaviour of the facade, the indoor thermal comfort, and the energy consumption of the adjacent apartments. Once this data was collated and the simulation tool was calibrated, it was then possible to generalise the results for a whole year. The simulation could then be utilised to modify the design of the solar wall to maximise its efficacy through the addition of shading devices and varying the insulation and ventilation characteristics. This allowed design changes to occur quickly, without having to wait a few more years for the data to be collated. Through the use of experimentation and simulation, the authors concluded that the solar wall was an efficient system for both thermal comfort and energy saving in a Mediterranean climate (Stazi, et al., 2012).

In order to answer research question two, the productivity of at least one city as a result of naturally-lit building integrated technical food systems must be known. This calculation will rely on the productivity metrics from the building integrated technical food systems, which will then be combined with the results of a light capture analysis of a computer-generated three-dimensional representation of a real-life UK city. This will allow the total productivity per annum of the chosen city to be estimated. The three-dimensional model itself will comprise of accurately created building blocks in plan which are then extruded to the building heights provided by LiDAR (Light Detection and Ranging) information. Pitched roofs will be omitted from the study due to the unknown productivity and complexities associated with farming upon an inclined plane. As a result, each building element will be modelled with a flat roof because for the purposes of simplicity and the negligible effects pitched roofs will have on overshadowing of adjacent buildings as a proportion of the total surface area of a city. The light capture analysis of a UK city will allow conclusions to be made relating to how effective cities are at capturing light. For example, the

percentage of the surface area of the built environment that captures sufficient light to ensure successful crop growth is currently unknown. Unlike the design of a technical food system, which can be improved to minimise complications of integration, cities exist as they are and are not capable, within the realms of possibility, of being changed to suit urban food production. Therefore, if cities suffer from too much overshadowing due to building density, then the future of urban agriculture is questionable. However, if through simulation research it is discovered that cities are capable of supporting crop growth upon most or all of its surface area, then urban agriculture could become a prosperous industry. By combining the area of the city that is capable of supporting crop growth with the metrics from the constructed technical food systems, it can be calculated how many crops the UK city in question can produce.

Once the productive capacity of a single UK city is known the data can be applied to all of the cities within the UK, to determine the productive capacity of the nation, as result of the implementation of naturally-lit building integrated technical food systems. Due to the method utilised for the light capture analysis, which will be explained in much greater depth in chapter six, it is not feasible at this stage to conduct light capture studies for each UK city to determine their respective productive capacity. Instead, the relationship between the geographical area of the initial city and the productive capacity of the initial city will be utilised to inform a simple metric that will determine food production per hectare per annum, which can then be applied to each UK city as a broad method of analysis. Although this method of inquiry will include some large assumptions, which will ultimately lead to an unknown margin of error, it will nonetheless provide a base point from which the impacts of naturally-lit building integrated technical food systems on UK food security and the mitigation of ecological damage can be calculated and discussed. Future research will then be required to refine and validate this figure further, to provide an improved indication of the impact of naturally-lit building integrated technical food systems.

An example of this type of approach that has been used in previous research is Rohinton Emmanuel's study into how the size and orientation of windows and paint colours can help in abating urban heat gains for Sri Lankan residents (1999) and the research by van Esch, Looman, and de Bruin-Hordijk (2012) in which the impact of

street orientation and width, in addition to different roof profiles, were used to generate a set of principles for passive urban cooling. In addition to this Stazi, Mastrucci and di Perna (2012), which has been discussed previously, have proven the success of combining experimental data with simulation research, which is the process of inquiry that will be utilised to answer research question two.

3.6.3 - Research question three

What are the potential social and economic benefits of implementing building integrated technical food systems within inner urban areas, and how might these benefits improve human wellbeing within urban environments?

Paradigm	
Method to be used	Simulation and logical argumentation
Ontological Position	Subjective
Epistemological Position	Emic (interactive)
Scale of Applicability	Mid-range
Data collected	Quantitative and qualitative

Tactic 1	
Study	How would the implementation of naturally-lit building integrated technical food systems affect the area of green space within cities?
Setting	Mathematical simulation.
Treatment	Comparison between the original green area of the chosen city compared with the maximum growing area of the chosen city.
Observations	Increase in urban green space.

Tactic 2	
Study	How many jobs could building integrated technical food systems provide within the chosen city of study?
Setting	Mathematical simulation.
Treatment	Calculate total worth of crops grown and omit monies reserved for profit and maintenance, leaving a figure that can be compared with the HMRC percentile earnings of the UK.
Observations	The number of jobs building integrated technical food systems could provide within the chosen city of study.

Tactic 3	
Study	What are the additional benefits of urban agriculture?
Setting	Logical argumentation.
Treatment	The building of logical conclusions based on the first principles identified by research question one and research question two.
Observations	The impact building integrated technical food systems can have in relation to the physical, psychological and financial wellbeing of urban inhabitants.

Research question three aims to understand the potential benefits of urban agriculture in addition to the growing of food. This final phase of research will also aim to quantify the increase in green space of the UK city studied as part of research question two and quantify how many jobs building integrated technical food systems might create in the future.

The first two attributes of research question three - i.e. the number of jobs created and the increase in urban green space - will rely upon the simulation data captured as part of research question two. This data will enable the total possible growing area within the chosen city to be determined and the increase in green space to be calculated. The annual productivity of the studied city will also allow conclusions to be made relating to the total sale value of the crops; enabling a very basic financial structure to be developed and the number of jobs created to be estimated. Again, much like research question two, the quantitative data documented as part of research question three will be a starting point from which further research can improve upon. Therefore, the data published in this thesis is intended as a springboard for further inquiry and to promote discussions and debates amongst both advocates and critics of urban agriculture to inform a deeper understanding of the subject area and potential urban lifestyles and design strategies. The second half of research question three will focus on the additional benefits of urban agriculture as a whole. Unlike the research goals associated with research questions one and two, research question three cannot be answered through the building and testing of physical experiments or virtual simulations. Instead, the potential benefits of building integrated technical food systems, and urban agriculture as a whole, will need to be postulated utilising the research methods associated with logical argumentation, until such a time occurs that there are enough urban agricultural interventions to assimilate the true benefits of agriculture within cities.

The method of logical argumentation is based on the use of key 'first principles', upon which broad explanations, conclusions or arguments can be built. Within this thesis, the first principles of research question three will have been identified and justified in research questions one and two, such as the maximum number of crops a city can produce, for example. Logical argumentation typically takes a set of previously unknown, unappreciated or un-unified factors and connects them together to form a unified framework that has a significant or novel explanatory power (Groat, et al., 2013). If the explanatory structure is successful, it provides new ways of looking at existing scenarios or phenomenon. For example, the number of crops grown within a city can enable the increase in urban green space to be calculated, which can then be linked with other existing research to identify how improved access to urban green space can affect the wellbeing of urban populations. In this

instance, the area of crop production is the first principle from which other conclusions can be drawn.

In summary, the knowledge created in answering the first two research questions will be utilised to inform the potential benefits of implementing building integrated technical food systems within inner-city areas. This is a key point of understanding as it will provide an insight into the potential futures of cities if urban agriculture was to become a large-scale reality. The benefits identified as part of research question three may also create a counterbalance to simple metrics, such as food production, when urban agriculture is being discussed with decision makers and urban planners in the future. As mentioned in the previous chapter, achieving food security is the combination of three key drivers, which are access, quality and quantity. If, for example, the quantity of food produced as a direct result of naturally-lit building integrated technical food systems is discovered to be low, such an endeavor may still be able to benefit urban populations in other ways, such as improving food quality, creating a known number of jobs, or by improving air quality. It is believed that in order for balanced and well-informed debates to take place relating to the future of urban agriculture, the many different potential impacts of the practice need to be identified and discussed, which is one of the key aims of research question three.

Obvious conclusions can be made relating to the implementation of urban agriculture such as 'jobs will be created' and 'the provision of green infrastructure will be increased'. However, at this moment in time it cannot be calculated just how many jobs would be created or by how much green infrastructure would increase. In order for these metrics to be calculated a technical food system needs to be built and tested (research question one) in order to determine how many crops can be grown within cities (research question two) so as to calculate the number of jobs that would be created and the increase in area of green area that would occur. Only through the lineage of research question one and research question two can the questions asked in research question three - i.e. the additional benefits of urban agriculture - be answered and discussed.

Now the method of inquiry for each research question has been identified and justified, it is of critical importance to understand the different techniques of food

production that are available within the urban context. Therefore, the following chapter will identify and analyse both soil-based and soilless growing techniques, including the two primary methods of nutrient delivery within technical food systems - i.e. hydroponic and aquaponic systems - and plant factories to determine the strengths and weaknesses of each method of food production within the urban context. Ultimately, conclusions will be made relating to which food production systems are most applicable within high-density cities, and more importantly, which are most suitable to be placed within or upon existing buildings. The information contained within the next chapter will help to determine which food system or systems should be taken forward to the design and construction stage of the thesis.

4.0

U R B A N

F O O D

P R O D U C T I O N

4.0 // URBAN FOOD PRODUCTION //

In the previous chapters, the need for further urban agricultural research was identified in response to the global food system and UK food security, as well as the lack of communicable knowledge relating to the technical challenges that face its integration and the conflicting opinions relating to the overall impact of urban agriculture. In this chapter, the different methods of growing food within cities are identified to create a database of urban food systems inclusive of both soil-based and soilless agricultural practices. This deeper understanding of urban food production allows conclusions to be made as to which methods are best suited to inner urban areas when comparing their complexity and resource needs, for example.

4.1 - Investigating urban food systems

In order to improve the food security of the UK, domestic food production needs to increase whilst simultaneously reducing ecological damage. With the intensification of food production believed to be reaching its theoretical biophysical limit and the extensification of food production ruled out in order to protect natural environments, the only available space left to grow food in the UK is within cities, and more specifically, within and upon buildings. Traditional agricultural techniques, such as ploughing the land to produce row crops, for example, are unsuitable methods of food production within inner urban areas due to the lack of wide open spaces. Hence, novel methods of food production are required to help improve food security, especially when considering the integration of food systems within and upon existing buildings. In order to investigate the possible impacts of urban agriculture, it is critical to identify and understand the different methods of food production that are available within urban environments to allow conclusions to be made relating both to their applicability and placement within high-density cities. The following chapter identifies and analyses both soil-based and soilless methods of food production and discusses, where appropriate, the strengths and weaknesses of each approach.

4.2 - Soil based urban food systems

The simplest method in which to grow food is to utilise the most abundant agricultural commodity available; soil. Soil is a mixture of decomposed organic matter, nutrients, minerals, gases, and a whole host of microorganisms that collectively promote the growth of food. Previously unused, well maintained or unexploited soils are rich in nutrients and minerals. However, over time these nutrients and minerals can be stripped away as a result of intense agricultural activities. In order to reverse this process and to promote further growth, the depleted nutrients have to be replaced, typically through the addition of minerals rich in nitrogen, phosphorus and potassium to the soil. Although growing food in soil is a tried and tested method of agriculture, stretching well over twelve thousand years, its use in cities is somewhat limited due to the lack of available space, and concerns over soil contamination as a result of historical and ongoing industrial processes.

4.2.1 - Urban soils and heavy metals

Historically, small settlements would manifest and thrive due to access to readily available resources. Many of these settlements would become centres for cottage industries, later developing and growing to become centres for heavy industry. As a result, many cities of today are built on the slag heaps, bleaching field and chemical dumps of early industrialisation. Although many modern cities in the developed world have pushed industry far away from their centres, soils within today's cities are still exposed to contamination through the atmospheric transport of contaminated dusts from anthropogenic activities such as vehicle emissions, industrial discharge and waste incineration (Gibson, et al., 1986; Harrison, et al., 1981; Thornton, 1991). As a result of historic heavy industry and modern human activities, the primary elements associated with the contamination of urban soils are Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel and Zinc (Christoforidis, et al., 2009) in addition to Selenium. The impacts these elements have on human health varies greatly at different concentrations, however, they all pose a risk above certain threshold values. The effects of these contaminants will be briefly discussed here.

Arsenic

If sufficient quantities of arsenic are swallowed - 6,000 ppm in water - arsenic can lead to death although a lower dose - 3,000 ppm - can lead to irritation of the stomach and intestines, including stomach ache, nausea, vomiting, and diarrhoea. Other effects include decreased production of red and white blood cells, abnormal heart rhythm, blood-vessel damage, and impaired nerve function. Exposure to arsenic can also lead to skin changes such as patches of darkened skin and the appearance of small warts on the palms, soles, and torso. Arsenic is a known carcinogen that can increase the risk of developing skin, liver and bladder cancer. If Arsenic dust is inhaled, it can lead to a sore throat and irritated lungs, which could later lead to the development of lung cancer. (ATSDR, 2007a)

Cadmium

Inhalation or consumption of low concentrations of cadmium over many years can result in the accumulation of cadmium in the kidneys, and if sufficiently high, can cause kidney disease. If sufficient enough quantities of cadmium are inhaled it can lead to severe damage of the lungs and nasal cavity, cause lung cancer, or even result in death. Consuming cadmium in high enough levels severely irritates the stomach, leading to vomiting and diarrhoea. Exposure to low levels of cadmium for many years can lead to brittle bones, anaemia and liver disease. Nerve or brain damage can also occur as a result of cadmium consumption (ATSDR, 2012a).

Chromium

The most common reactions to chromium exposure in the air are irritation of the nasal lining, a runny nose, and breathing problems such as asthma, coughing, shortness of breath and wheezing as well as skin rashes. When chromium is consumed, it can lead to irritation and development of ulcers in the stomach and small intestine along with the possibility of developing anaemia. Damage to the male reproductive system can also occur inclusive of damage to sperm. Chromium is a known carcinogen to humans and can lead to the development of lung cancer along with the development of tumours in the stomach, intestinal tract and lungs (ATSDR, 2012b).

Copper

Copper, unlike some of the other heavy metals noted, is essential for good health, although it can lead to problems if consumed in high enough doses. Inhalation of sufficient copper dust can lead to nose, mouth and eye irritation, causing headaches, dizziness, nausea and diarrhoea. Consumption of copper can lead to nausea, stomach cramps, vomiting and diarrhoea. Very high intakes of copper can cause kidney and liver damage and can even lead to death. Copper is not considered to be a carcinogenic (ATSDR, 2004).

Lead

The effects of lead exposure are the same regardless of whether the element is swallowed or inhaled. The primary effects of lead exposure are directed towards the body's nervous system. Long-term exposure to lead can result in decreased mental performance and can also cause weakness in fingers, wrists and ankles. Lead exposure can cause increased blood pressure in middle-aged and older people as well as leading to the development of anaemia. High levels of exposure in adults or children can result in severe brain and kidney damage, which can cause death. Exposure to high levels of lead can also result in the miscarriage of unborn children and damage to the testicles leading to decreased sperm production. Lead is considered to be a probable carcinogen (ATSDR, 2007b).

Mercury

Metallic mercury vapours or organic mercury may affect many different areas of the brain and their associated functions, resulting in a variety of symptoms. These include personality changes (irritability, shyness, nervousness), tremors, changes in vision (constriction or narrowing of the visual field), deafness, muscle incoordination, loss of sensation, and difficulties with memory. All forms of mercury can cause kidney damage if sufficient amounts enter the body and inorganic mercury can also damage the stomach and intestines, producing symptoms of nausea, diarrhoea, or severe ulcers if swallowed in large amounts. Short-term exposure to metallic mercury vapours, over the course of a few hours, can damage the lining of the mouth and irritate the lungs and airways, causing tightness of the chest, a burning

sensation in the lungs, and coughing. Other effects from exposure to mercury vapour include nausea, vomiting, diarrhoea, increases in blood pressure or heart rate, skin rashes, and eye irritation. Skin contact with metallic mercury has been shown to cause an allergic reaction in some people. Effects on the heart have also been observed in children after they accidentally swallowed mercuric chloride. Symptoms include rapid heart rate and increased blood pressure. Mercury chloride and methylmercury are considered to be possible human carcinogens (ATSDR, 1999).

Nickel

The most common reaction to nickel is an allergic reaction. Between ten and twenty percent of people are sensitive to nickel exposure. This reaction can be in the form of a skin rash or dermatitis. Consumption can lead to stomach aches and adverse effects in the blood and kidneys. When inhaling high doses of nickel the most serious effects are chronic bronchitis, reduced lung function, and cancer of the lungs and nasal sinus (ATSDR, 2005a).

Selenium

Much like copper, selenium is an essential nutrient. In very high doses, however, selenium inhalation can lead to dizziness and fatigue, as well as irritation of the mucous membranes. In very extreme cases selenium exposure can lead to pulmonary oedema (liquid in the lungs) and severe bronchitis. If high doses of selenium are consumed, it could lead to death if medical treatment is not sought quickly. Long-term exposure to selenium can lead to brittle hair and deformed nails. Deficiencies in selenium can also be an issue resulting in heart problems and muscle pain. Contact with the skin of industrial selenium can result in rashes, redness, swelling and pain. Very high exposures to selenium could result in decreased sperm count, increased abnormal sperm and changes in reproductive cycles and the menstrual cycle. Selenium is not considered to be a carcinogen (ATSDR, 2003).

Zinc

Zinc is also an essential nutrient, but the inhalation of large quantities of zinc can result in short-term illness such as metal fume fever. If large doses of zinc are consumed, it can lead to the development of stomach cramps, nausea and vomiting. Ingesting high levels of zinc for a long period of time can cause anaemia and damage to the pancreas and kidneys. Skin irritation can result from contact with zinc. Zinc deficiency can also be an issue, leading to loss of appetite, decreased sense of taste and smell, decreased immune functionality and slow healing of wounds. Long-term zinc deficiency can lead to poorly developed sexual organs and decreased growth in young men and birth defect in babies. (ATSDR, 2005b)

4.2.2 - Urban soils for food production

For conclusions to be made relating to the possible risks of soil contamination within urban centres it is imperative to determine what levels of exposure are considered safe with regards to food production. Determining these levels of exposure is best achieved through the combination of the European Union Directive 86/278/EEC, which forms the Code of Practice for Agriculture Use of Sewage Sludge within the UK (Department for the Environment, 1989), the Government Decree on the Assessment of Soil Contamination and Remediation Needs (Ministry of the Environment, 2007) and the element specific appendices of the Development of Category For Screening Levels for assessment of land affected by contamination (C4SLS) (Environment Agency, 2009a, Environment Agency, 2009b; DEFRA, 2014a; DEFRA 2014b; DEFRA 2014c; DEFRA 2014d; DEFRA 2014e). Together, these three reports provide a wealth of information regarding the concentrations of contaminants within soils, focusing on large-scale food production, ecological and human damage, as well as food grown in soil for personal consumption. The Code of Practice for Agriculture Use of Sewage Sludge identifies the maximum permissible levels of contamination in agricultural soils, which is used throughout the UK to help improve food safety. The Government Decree on the Assessment of Soil Contamination and Remediation Needs identifies the threshold, lower and upper levels of soil contamination with regards to ecological and human harm, where the threshold value is considered the 'background value'. The lower guideline value of this report is where damage starts to occur, and the high guideline value is where

severe damage occurs. The Development of Category For Screening Levels for assessment of land affected by contamination report (C4SLS) identifies the maximum permissible concentration of contaminants within soils that produce food for personal consumption such as gardens and allotments. The information relating to the contaminants noted previously (Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium and Zinc) were extracted from these three reports and brought together to form an overview of permissible levels of soil contamination. These figures can be seen below.

Table 4.1 - Collated soil contamination data relating to large-scale food production, ecological and human damage, and food grown for personal consumption

Element	Government Decree			C4SLS		EEC
	Threshold (mg kg ⁻¹)	Lower (mg kg ⁻¹)	Higher (mg kg ⁻¹)	Residential (mg kg ⁻¹)	Allotment (mg kg ⁻¹)	86/278/EEC (mg kg ⁻¹)
Arsenic	5	50	100	37	49	-
Cadmium	1	10	20	14	2.4	3
Chromium	100	200	300	6.1	120	400
Copper	100	150	200	-	-	135
Lead	60	200	750	82-210	30-84	190
Mercury	0.5	2	5			1
Nickel	50	100	150	130*	230	75
Selenium	-	-	-	350*	120	-
Zinc	200	250	400	-	-	20

* No indication is given in the report as to whether the concentration of residential soil is to include for residential soil utilised for food production

Once this information was consolidated, it was important to determine which of these values would be utilised to represent the threshold and upper limit of soil

contamination for each named contaminant in the context of urban food production. This was achieved through the development of a set of rules that are noted below.

- Where possible the EEC Directive was taken as the maximum concentration of contamination for agricultural soils unless this value was considered to represented a risk to human health within the Government Decree report. In which case the value within the Government Decree report would be taken as the upper value.
- Where there is no information for the element in question within the EEC Directive, the highest value across the three reports is taken.
- Where there is a range of values that form the upper value, it is the largest figure across that range that will be taken to represent the upper value.
- Where there is a range of values that forms the lowest value, the lowest figure across that range will be taken to represent the threshold value.
- Where only two values are present for a single contaminant, these figures will be taken to represent the threshold and upper values.
- In the instance where the EEC Directive 86/278/EEC value given is the lowest of all the values, this value will represent both the minimum and the maximum value for that element.

Based on these rules, the resultant threshold value and upper value for each contaminant in the context of food production within urban soils can be seen in table 4.2.

Table 4.2 - Resultant threshold and upper levels of soil contamination when growing food in urban soils for human consumption

Element	Threshold value for urban agriculture (mg kg⁻¹)	Upper value for urban agriculture (mg kg⁻¹)
Arsenic	5	50
Cadmium	1	3
Chromium	6.1	200
Copper	100	135
Lead	30	190
Mercury	0.5	1
Nickel	50	75
Selenium	120	350
Zinc	20	20

Once it had been determined above what levels of soil contamination food production would not be safe within urban environments, it was then possible to combine these figures with known soil data to conclude what proportion of urban soils are capable of supporting safe food production. In this instance, the soil data used was taken from the London Earth Project, which was commissioned by the British Geological Survey. This systematic soil survey across the Greater London Area gives an insight into the environmental impacts of urbanisation and industrialisation, as well as providing baseline values for over 50 elements. Included in this survey is data relating to eight previously noted and potentially dangerous elements; arsenic, cadmium, chromium, copper, lead, nickel, selenium, and zinc. Unfortunately, the data relating to mercury is not publically available, which omits this element from further analysis. An example of this data can be seen in figure 4.1; representing the concentrations of lead within the Greater London Area. For all of the contamination data sheets relating to the London Earth project, please refer to Appendix A.

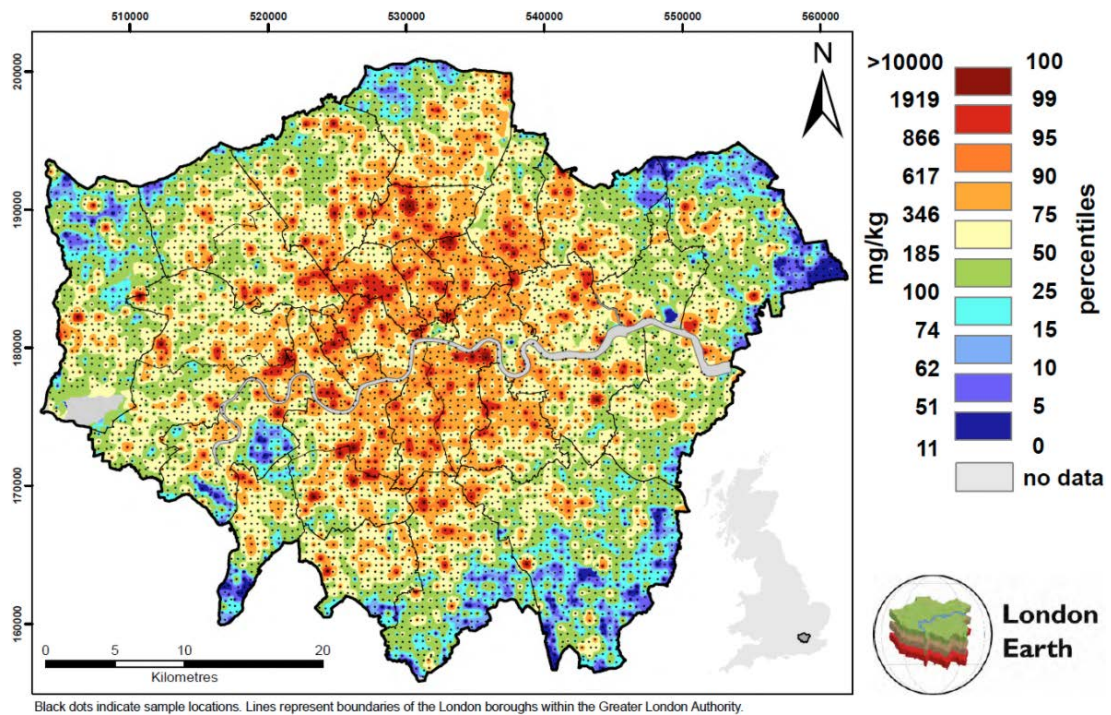


Figure 4.1 - London Earth: Pb in surface soils (British Geological Survey, 2011)

By combining this soil data with the figures for the threshold and upper values of soil contamination for urban agriculture, it can broadly be determined how urban soils would affect ground-level food production, if food was to be grown directly in native soils. The resulting table (table 4.3) identifies what proportion of urban soil would be capable of supporting safe food production equal to or below the threshold value of soil contamination, and what proportion of urban soil would be capable of supporting safe food production equal to or below the upper value of soil contamination. It should be noted, however, that due to the way in which the data is presented in the London Earth project - as a gradient of colour that classifies data in a logarithmic style, where in some cases one colour can represent a large spread of results - it is necessary to round the threshold or upper value up or down to the nearest percentile represented in the study. An example of this would be the upper value of soil contamination for lead; noted as 190 mg kg^{-1} . The nearest value to this in the London Earth data is 185 mg kg^{-1} , where 50 percent of the samples taken are below, or equal to, 185 mg kg^{-1} . In this instance, the value of 50 percent is taken to represent the area of land that is safe for food production based on the upper value of 190 mg kg^{-1} . As a result, the given percentages of usable soil within the Greater London Area for each element is only for guidance to represent a general

understanding that soil within urban centres is contaminated to varying levels and would affect the production of safe food in some way.

Table 4.3 - Proportion of London's native soil that is safe for agricultural practices

Element	Threshold value (mg kg ⁻¹)	Area of London suitable	Upper value (mg kg ⁻¹)	Area of London suitable
Arsenic	5	0%	50	99%
Cadmium	1	75%	3	95%
Chromium	6.1	0%	200	99%
Copper	100	75%	135	90%
Lead	30	0%	190	50%
Nickel	50	95%	75	99%
Selenium	120	100%	350	100%
Zinc	20	0%	20	0%

Dependent on how one views this data, the results of this analysis can be interpreted in different ways. For example, if viewing the upper limit of contamination only, it can be seen that a large proportion of London's native soils are within the bounds of the study. However, based on the upper value for zinc contamination, none of London's native soils would be suitable for crop growth. When looking towards the safer end of the spectrum - i.e. the threshold value for urban agriculture - the native soils within the Greater London Area do not meet the requirements for safe food production when analysing the presence of arsenic, chromium, lead and zinc. Realistically, the production of food in native soil within the Greater London Area would not be as black and white as the above table suggests, due to the identification of a range of values that represent safe food production within this thesis. For example, dependent on what level of contamination for arsenic is deemed safe for food production by local authorities in the future, would determine whether one percent or ninety-nine percent of urban soils were suitable for crop production.

It is clear from this analysis that the contamination of native soils is an issue when considering food production within urban environments. However, the impact native soils can have on food production can be minimised or almost entirely eliminated through the implementation of a multitude of different approaches, which can reduce the risks contaminated soils pose to urban food production. This can typically be achieved through the use of raised beds or by implementing soil-based agriculture on top of roofs; both of which will be discussed further. For the purposes of clarity, allotments have not been included in this analysis because they typically exist on the periphery of cities, where building density is lower, and availability of land is less competitive.

4.2.3 - Raised beds

Raised beds, in their many shapes and sizes, are the most cost-effective way of separating soils deemed safe for food production from soils with high levels of contamination. Not only can raised beds create a barrier to contaminated soils, through the use of impervious membranes, but they also raise the height of the arable surface to a more desirable level, reducing back and leg strain commonly experienced when working at ground level. This elevated working plane also allows those suffering from disabilities, who would otherwise struggle to work at ground level, the opportunity to grow food if the growing plane is raised to a sufficient height. Raised beds are a simple and cost-effective solution to food production within cities but they rely on the importation of vast quantities of soil as well as the inefficient use of water due to excessive evaporation, and a resource that is in very short supply within high-density cities; i.e. available space. Due to this, raised beds are not typically considered a scalable method of food production within high-density cities because they can only ever be as big as the space left over in between buildings. They do, however, offer an opportunity for peace and relaxation within busy urban environments, while improving the provision of green infrastructure, promoting social cohesion, and improving the wellbeing of the urban inhabitants which utilise them. Examples of raised bed agriculture within different urban contexts can be seen in figure 4.2, figure 4.3 and figure 4.4



Figure 4.2 - Alice Street Community Gardens - Boston, USA

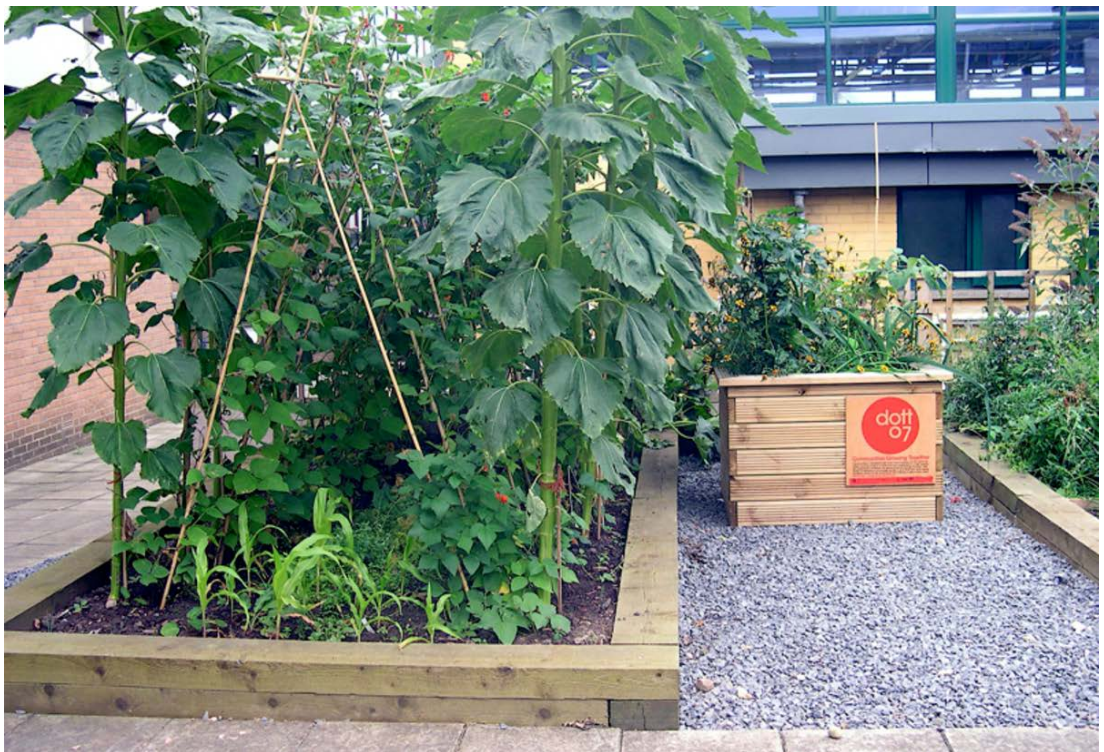


Figure 4.3 - Middlesbrough Urban Farming Project - Middlesbrough, UK



Figure 4.4 - Southeast False Creek Temporary Community Garden - Vancouver, Canada

4.2.4 - Roof gardens

As mentioned previously, the rooftops of buildings are also a possible site for soil-based agriculture. Roof spaces are typically left vacant and underutilised for the duration of the building's life, whilst costing money to maintain. Within cities, flat roofs are the perfect location in which to grow food as they are less prone to overshadowing and offer larger agricultural footprints when compared with soil-based agriculture at ground-level within high-density cities. That being said, there is one fundamental problem facing the integration of soil-based rooftop agriculture, which needs no consideration at ground level, and that is the weight of the soil. The roof structures of both modern and historic buildings are built to support relatively small loads. This is because there is only one realistic situation in which a vertical load is applied to a flat roof and that is standing snow. Hence, roofs are not typically built to support the weight of soil-based agriculture. When growing food in a raised bed, a traditional depth of soil is deemed to be 300 millimetres, to provide a sufficient area for root growth and drainage. In the UK, the British Standards Institution states that a roof must be able to support its own weight plus a minimum

imposed load of 1.5kN/m^2 (approximately 150kg/m^2) (British Standards Institution, 1998). Agricultural soils suitable for crop growth, on the other hand, can weigh anything from $1,100\text{kg}$ to $1,600\text{kg}$ per cubic metre depending on soil density (United States Department of Agriculture, n.d.), which is between ten and sixty percent heavier than water. To achieve a depth of 300mm for successful root growth and drainage, the weight of soil would be between 330kg to 480kg , which does not take into account the additional load of the soil when wet or the additional live load of people walking on the roof. Realistically, to support soil-based agriculture roof constructions would need to be a factor of between three and four times stronger to support the weight associated with the practice. Even if soil-based practices were adopted on the intermediate floors of a building - where the floor plates are stronger due to continual occupation - the loads exerted on the structure would still be above the minimum requirements for imposed loads in office buildings of 2.5kN/m^2 (approximately 250kg/m^2) (British Standards Institution, 2002).

The issues relating to the structural support of soil-based systems, however, can be overcome in some instances. One option to mitigate the impacts of this problem is to design a new building with the intent of growing food on the roof. This foresight allows structural calculations to be made and construction drawings to be updated before work begins so that the roof can safely support the weight of soil required (see figure 4.5). Another option is to grow food in very shallow grow beds, for the purposes of growing very small crops such as herbs to stay under the loading limits of the roof (see figure 4.6). In rare instances, existing buildings are capable of supporting soil-based agriculture. In these cases, the initial roof design was more than likely built with a secondary use in mind, where additional loading would be required for large exterior machinery, for example (see figure 4.7). Alternatively, existing roofs can be strengthened to support the additional loads at a cost to the building owner. Ultimately, for a roof to carry more load, it needs to be built with deeper steel sections which increases build cost as a result. In the majority of cases, it is unlikely that the developer or building owner will pay for any additional loading unless it is required; vying for the cheapest option that will satisfy the building regulations. It should be noted at this point that there is a significant difference between growing food on rooftops and growing food on rooftops safely. Whilst it may be possible to support deep soil-based agriculture on a typical flat roof in the short term, these actions could lead to issues such as water ingress, structural damage, or

structural failure. It is therefore vitally important that any addition of weight to a rooftop is appraised by a structural engineer before work commences, to ensure the safety of those that want to grow crops at such a height, and those that live or work beneath it.



Figure 4.5 - Gary Comer Youth Centre - Chicago, USA



Figure 4.6 - Nobel Rot Restaurant Roof Garden - London, UK



Figure 4.7 - Brooklyn Grange - Brooklyn, USA

4.2.5 - Urban soil-based agriculture summary

Soil-based agriculture has been a proven practice for thousands of years, but within high-density cities, it may not be the best method in which to grow food. Native soils can contain dangerous levels of arsenic, cadmium and lead amongst other contaminants and although there are ways and means of separating food production from contaminated soils, through the use of raised beds and roof gardens, there are still difficulties relating to its integration, scale and productivity. For example, raised beds are a cost-effective method of separating contaminated soils from food production, but within high-density cities, they are likely to be small in scale due to the space available between buildings. Alternatively, the utilisation of roof space offers a much larger share of the city, but there are fundamental safety issues relating to the placement of soil-based agriculture on the roofs of existing buildings, due to the inability of existing roofs to support the loads exerted by deep, wet soil. This issue can be remedied to a certain extent through structural improvements to existing buildings, but there would be a cost associated with this work. If known well in advance, soil-based agriculture can be factored into new buildings, and the additional loading exerted upon the structure can be calculated and designed accordingly. However, this again poses issues relating to scalability because the likelihood of each new building within a city having a roof garden is potentially quite small, and the overall contribution of new buildings to the collective building stock will be relatively low; resulting in only a handful of agricultural roofs.

The combination of contaminated native soils, poor scalability, difficulty of integration at roof level and high resource use - primarily soil and water - makes soil-based agriculture an unrealistic option for large-scale food production within high-density cities. As a result, future localised food production would need to depend on alternatives to soil-based practices, that can be large in scale and integrated within and upon existing buildings without the need for structural alterations, as well as minimise resource use when producing fresh food. These alternative methods of food production within cities could include the use of technical food systems, for example, which grow food directly in water; reducing water use and the need for heavy soil.

4.3 - Water based systems

Water-based agricultural systems - also known as technical food systems or soilless agriculture - are hybridised food systems that utilise technical products such as glass, plastic, and mechanical pumps, to grow food directly in nutrient-rich water. Growing crops in this way maximises production and shortens harvest cycles, leading to more productive systems (Bernstein, 2011). This is due to the nutrient solution, which is in direct contact with the roots, making it easier for crops to acquire the macro and micronutrients they require to grow. There are two recognised methods of nutrient delivery associated with technical food systems, which are hydroponic and aquaponic systems. These two different approaches utilise similar equipment to grow food, but the way in which they make nutrients available to crops is very different. These nutrient delivery systems share a common lineage, which started with the development of hydroponic systems as a direct result of experiments that were designed to determine plant nutrition in the early seventeenth century, and later led to the development of aquaponic systems when aquaculturists experimented with filtration utilising plants in the late 1970's.

4.3.1 - The history of hydroponic systems

The study of hydroponic systems can be defined as *“the science of growing plants without the use of soil, but by the use of an inert medium, such as gravel, sand, peat, vermiculite, pumice, perlite, coco coir, sawdust, rice hulls, or other substrates, to which a nutrient solution is added, containing all the essential elements needed by a plant for its normal growth and development”* (Resh, 2013, p. 2). The floating gardens of the Aztecs and the hanging gardens of Babylon were early examples of hydroponic systems, and Egyptian hieroglyphics record the growing of plants in water over two thousand years ago. The systematic development of hydroponic food systems was an evolution of plant nutrition science which began in 1600 with an experiment, designed by Jan Baptista van Helmont, to discover plant nutrition. This experiment consisted of planting a five-pound (2.3kg) willow shoot in a tube containing 200-pounds (90.7kg) of dried soil. After five years of regular watering with rainwater, Helmont found that the soil had lost two ounces in weight whereas the willow shoot had increased by 160 pounds (72.5kg). His conclusion at the time was that plants obtained their nutrients from water but failed to realise that they also

required carbon dioxide and oxygen from the air. In 1699, this basic understanding of plant nutrition was further improved when John Woodward grew plants in water with different quantities of dissolved soil. Woodward found that the greatest growth occurred in water that contained the most soil, which led to the understanding that plant growth was a result of certain substances in the water, derived from soil, rather than simply from the water itself (Korcak, 1992).

One hundred years separated these two poignant observations, but it would be over two hundred years before plant science advanced again. In the mid-1800's Boussingault - a French chemist - confirmed that water was essential for plant growth as water provided the plant with hydrogen. The dry matter of plant was found to contain hydrogen plus carbon and oxygen, which was taken from the air, along with nitrogen and other mineral elements (Wisniak, 2007). This later led to the development of an experiment in which plants were grown in different inert mediums, such as sand, quartz and charcoal onto which solutions with known chemical concentrations were added. The healthy growth of the plants confirmed that plants could be grown in an inert medium moistened with a water solution containing the nutrients required by plants for sustained growth; the basic principle of a hydroponic system. A decade later, two German scientists, Sachs and Knop removed the media entirely, demonstrating that normal plant growth can be achieved by immersing the roots of a plant in a water solution containing salts of nitrogen, phosphorus, sulfur, potassium, calcium, and magnesium, which are now defined as the macroelements or macronutrients required by plants to grow; defining the origin of 'nutriculture' (Stiles, 1951).

The commercial use of nutriculture did not develop any further until 1925 when the greenhouse industry started to take note of the research. Nutriculture was seen at the time as a possible alternative to soil-based agriculture where soils within large commercial greenhouses would need to be frequently replaced to overcome problems of soil structure, fertility, and pests. In the early 1930s, W.F. Gericke of the University of California started to commission laboratory experiments into plant nutrition on a commercial scale. During this period, he termed these nutriculture systems 'hydroponics', which was derived from the two Greek words hydro (water) and ponos (labour), which translated into 'water working'. The first crops to be grown commercially were root crops such as radishes, carrots, and potatoes, as well as

cereal crops, fruits, and flowers. Initially the American press made many irrational claims, calling it the discovery of the century, but after an unsettled period, further research was conducted, and hydroponic systems became established on a sound scientific understanding, with recognition for its two key advantages; higher crop yields and the ability to grow food in non-arable regions across the world. The ability of hydroponic systems to grow crops in non-arable regions became extremely useful when providing food for troops stationed on rocky islands in the Pacific during the 1940's. During the 1950's the rest of the world started to pay attention to hydroponic food systems and many were constructed in Italy, Spain, France, England, Germany, Sweden, the USSR, and Israel.

Today large-scale hydroponic installations have become a reality in virtually all climates around the world, and there are now a number of hydroponic greenhouses in Canada, the United States and Mexico which exceed twenty hectares or more. The area covered by hydroponic food systems across the globe has increased from between 5,000 and 6,000 hectares in the 1980s to between 20,000 and 25,000 hectares in 2001 (Carruthers, cited in Resh, 1999) and more recent studies have suggested that hydroponic growing occupies approximately 35,000 hectares (Hickman, 2011). Hydroponic food systems are even being explored as a viable method for food production in space, with closed-loop recirculation systems being designed and tested on the international space station to see if such systems could sustain astronauts during long missions.



Figure 4.8 - Mizuna lettuce growing aboard the International Space Station

4.3.2 - Soil versus soilless food systems

The main advantage of soilless systems is the increased yields that are documented when compared with established soil-based practices. In both hydroponic and aquaponic systems, crop roots are in direct contact with nutrient-rich water. As such, the crops use little energy in acquiring the nutrients they require and can instead, utilise a larger proportion of their energy reserves to produce mass. When compared with open-air agricultural food systems, yield increases of technical food systems can be between four and ten times greater (Bernstein, 2011). Some of the causal factors that may result in these differences are a lack of nutrients in the soil, poor soil structure and the presence of disease or pests within the soil itself. In addition to this, soilless food systems can also accommodate higher density crop production, which when combined with continually renewed and readily available nutrients can further increase the productivity of hydroponic and aquaponic food systems in comparison to traditional agricultural practices (see table 4.5). Hydroponic and aquaponic food systems are technically described as ‘recirculating systems’ because the water within the system is primarily a carrier of nutrients, which is circulated continually to deliver nutrients to the crops. An additional benefit of

recirculating systems is that evaporation can be minimised by reducing the surface area of the water that is open to the air, and within a typically covered technological food system, evaporation and transpiration can be condensed and recovered if deemed necessary. As a result, the water consumption of technical food systems can be reduced by up to ninety percent, when compared with traditional soil-based practices (Bernstein, 2011).

Table 4.5 - Comparative yields per acre in soil and soilless culture (Resh, 2001)

Crop	Soil (lb)	Soilless (lb)
Soya	600	1550
Beans	10,000	42,000
Peas	2,000	18,000
Wheat	600	4,100
Rice	1,000	5,000
Oats	1,000	2,500
Beets	8,000	24,000
Potatoes	16,000	140,000
Cabbage	13000	18000
Lettuce	9000	21000
Tomatoes	10,000 - 20,000	120,000 - 600,000
Cucumbers	7,000	28,000

Due to the omission of soil from the practice of growing food, water-based food systems can also be much lighter; in some cases only requiring a centimetre or so of water to grow food. Due to this, they offer a serious alternative to soil-based agriculture when considering the structural capacity of existing buildings in high-density cities. In addition to this, the growing plane can be easily elevated to a more suitable level to reduce leg and back strain when maintaining and harvesting crops; increasing productivity and improving working conditions as a result. The

recirculating water required by both aquaponic and hydroponic food systems must be taken from a central reservoir, which raises issues relating to the support of the supplementary equipment, but in general terms, the weight reduction when compared to soil-based agriculture is significant, greatly increasing the possibility and probability of integrating such systems into the existing built environment. Soilless food systems also offer a wealth of other additional benefits, which include decreased weed control, improved quality of food, improved hydration of crops, and improved sanitation, for example, which can be seen in table 4.6.

Table 4.6 - Advantages of soilless culture versus soil culture (Resh, 2013)

Practice	Soil Culture	Soilless Culture
Sterilization of growing medium	Steam, chemical fumigants; labor intensive; time required is lengthy; minimum 2–3 wk	Steam, chemical fumigants with some systems; others can use bleach or HCl; short time needed to sterilize
Plant nutrition	Highly variable, localized deficiencies; often unavailable to plants because of poor soil structure or pH; unstable conditions; difficult to sample, test, and adjust	Controlled; relatively stable; homogeneous to all plants; readily available in sufficient quantities; good control of pH; easily tested, sampled, and adjusted
Plant Spacing	Limited by soil nutrition and available light	Limited only by available light, making, closer spacing possible; increased number of plants per unit area, resulting in more efficient use of space and greater yields per unit area
Weed control, cultivation	Weeds present, cultivate regularly	No weeds, no cultivation
Diseases and soil inhabitants	Many soil-borne diseases, nematodes, insects, and animals, which can attack crop; frequent use of crop rotation to overcome buildup of infestation	No diseases, insects, animals in medium; no need for crop rotation

Water	Plants often subjected to water stress because of poor soil–water relations, soil structure, and low water-holding capacity. Saline waters cannot be used. Inefficient use of water; much is lost as deep percolation past the plant root zone and also by evaporation from the soil surface	No water stress. Complete automation by use of moisture-sensing devices and a feedback mechanism. Reduces labor costs, can use relatively high saline waters, efficient water use, no loss of water to percolation beyond root zone or surface evaporation; if managed properly, water loss should equal transpirational loss
Fruit quality	Often fruit is soft or puffy because of potassium and calcium deficiencies. This results in poor shelf life	Fruit is firm, with long shelf life. This enables growers to pick vine-ripened fruit and ship it long distances. In addition, little, if any, spoilage occurs at the supermarket. Some tests have shown higher vitamin A content in hydroponically grown tomatoes than in those grown in soil
Fertiliser	Uses large quantities over the soil, nonuniform distribution to plants, large amount leached past plant root zone (50%–80%), inefficient use	Uses small quantities, uniformly distributed to all plants, no leaching beyond root zone, efficient use
Sanitation	Organic wastes used as fertilizers onto edible portions of plants cause many human diseases	No biological agents added to nutrients; no human disease organisms present on plants
Transplanting	Need to prepare soil and uproot plants, which leads to transplanting shock. Difficult to control soil temperatures and disease organisms, which may retard or kill transplants	No preparation of medium required before transplanting; transplanting shock minimized, faster “take” and subsequent growth. Medium temperature can be maintained optimum. No disease present

Plant maturity	Often slowed by non optimum conditions	With adequate light conditions, plant can mature faster under a soilless system than in soil
Permanence	Soil in a greenhouse must be changed regularly every several years since fertility and structure break down	No need to change medium in gravel, sand, or water cultures; no need to fallow. Sawdust, peat, coco coir, vermiculite, perlite, rockwool may last for several years between changes with sterilization
Yields	Greenhouse tomatoes 15–20 lb/yr/plant	Greenhouse tomatoes 50–70 lb/yr/plant

4.3.3 - Hydroponic food systems

Hydroponic systems typically consist of a water reservoir, a water pump and crops in some form of tray or channel. Hydroponic systems typically utilise mineral salts to provide the essential nutrients for crop growth, which are added either manually or automatically into a recirculated water system. Hydroponic systems operate by first pumping the nutrient-rich water from the reservoir up to the crops where the nutrients are taken up by the roots, and then allowing the water to fall back to the reservoir under the force of gravity, ready to be pumped around the system over and over again. As a result of this process, the nutrients within the reservoir gradually deplete and have to be restored at regular periods to ensure continued growth.

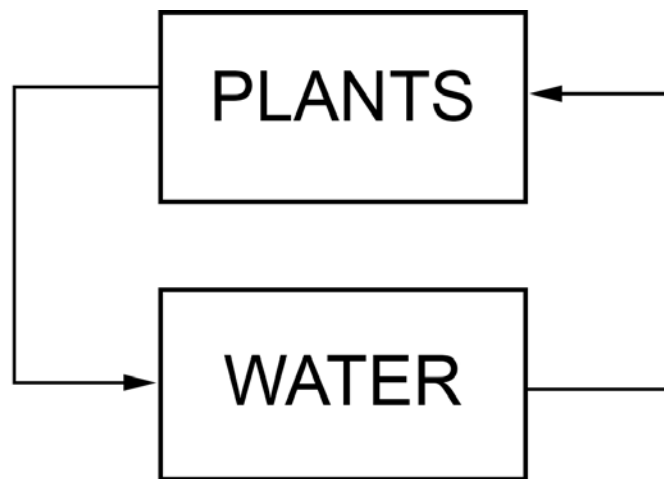


Figure 4.9 - Basic schematic of a hydroponic food system

4.3.4 - Hydroponic nutrient delivery and water use

Depending on the season of the year and the stage of crop development, the uptake of nutrients added to the systems occur at different rates, leading to the accumulation of some elements and depletion of others. The only way to accurately measure just how deficient the solution is with regards to a specific element at any one time is through the use of atomic absorption analysis. Such analysis, however, is a costly endeavour for those that do not have access to the expensive equipment required, and consequently, many are unable to perform such an analysis of the nutrient solution. A less costly and equally less effective method of analysing nutrient concentration is through the use of an electrical conductivity probe. When the concentration of available nutrients is high, it more readily conducts an electric current. The desired range for a hydroponic system is between 2.0 and 4.0 millimhos per centimetre (mmho/cm). Any measured conductivity above 4.0 mmho/cm may result in wilting and suppressed growth whereas any measured conductivity below 1.5 mmho/cm would lead to a loss in osmotic pressure, slowing the absorption process associated with the roots. The process of measuring nutrient availability through electrical conductivity, however, only determines whether there are available nutrients present. It does not provide any information as to which nutrients have accumulated and which have depleted. Therefore, the only cost-effective safeguard against nutrient depletion is to change the entire water supply of the hydroponic system periodically and re-establish the nutrient solution concentration to a known value for optimum crop growth. In a closed recirculating water system, where the

nutrient solution is drained back to the reservoir after use, the life of the nutrient solution is typically two to three weeks. During periods of high-yield summer months, the life of the nutrient solution may be as low as one week, although advancements in monitoring systems and sterilisation are pushing the longevity of nutrient solutions to approximately two months within hydroponic systems (Resh, 2013). Regardless of the longevity of the nutrient solution, the fact remains that to maintain predictable crop growth, the entirety of the water within the system has been discarded and replaced with fresh water to start the cycle again, which raises questions relating to inefficient water and nutrient use.

In addition to the challenges faced with regards to nutrient availability, the pH of the nutrient solution also changes over time as a result of reactions with the aggregate and the unbalanced absorption of the anions and cations within the solution, which can lead to a decreased quality of crop and decreased rates of growth. The various fertiliser salts that are used to form the nutrient solution also have different solubilities. If a nutrient salt has a low solubility, only small amounts of it will dissolve in water. Therefore, mineral salts with high solubility must be used so they remain in the solution (Resh, 2013). This restricts the type of minerals that can be utilised within the system and ultimately affects the purity of the nutrients being added to the water supply, due to the use of inert carriers such as silt, clay and sand. Therefore, these impurities need to be taken into consideration when calculating the quantities needed to produce the most effective nutrient solution. Some examples of nutrient purity can be seen in table 4.7.

Table 4.7 - Percentage purities of commercial fertilisers (Resh, 2013)

Salt	Purity (%)
Ammonium phosphate (NH ₄ H ₂ PO ₄) (food grade)	98
Ammonium sulfate ((NH ₄) ₂ SO ₄)	94
Ammonium nitrate, pure (NH ₄ NO ₃)	98
Calcium nitrate (Ca(NO ₃) ₂)	90
Calcium chloride (CaCl ₂ ·2H ₂ O) 77	77
Calcium sulfate (CaSO ₄) (Gypsum) 70	70
Monocalcium phosphate (Ca(H ₂ PO ₄) ₂) (food grade) 92	92
Monopotassium phosphate (KH ₂ PO ₄) 98	98
Magnesium sulfate (MgSO ₄ ·7H ₂ O) 98	98
Potassium nitrate (KNO ₃) 95	95
Potassium sulfate (K ₂ SO ₄) 90	90
Potassium chloride (KCl) 95	95

4.3.5 - Urban hydroponic food systems summary

In summary, hydroponic systems are typically reliant on excavated and man-made minerals for food production, and as a result, such systems are heavily dependent on the use of fossil fuels. Although research is being conducted into organic and naturally occurring fertilisers for hydroponic use, such as seaweed extracts and worm tea, for example, it has been found that these currently lack the full complement of macro and micronutrients required. The need to regularly refresh the nutrient solution results in large volumes of water being discarded, along with nutrients that have not been fully utilised. Hydroponic food systems also require regular human intervention to ensure a stable system and continued crop growth. That being said, hydroponic systems do have some advantageous characteristics that make them a great option for agricultural production within urban centres. In

comparison to soil-based agriculture, hydroponic systems are very lightweight, making their integration upon or within buildings a much more realistic proposition. Even though hydroponic systems require the frequent dumping of water, they still utilise much less water than traditionally irrigated agricultural techniques. The placement of hydroponic systems under glass or plastic creates a protective environment, which increases resilience to shock events such as storms, prolonged rainy periods, temperature drops or dry spells, which helps to improve food security as a result. Hydroponic agriculture seems to be a viable method of food production within high-density cities, but its use of mined fertilisers and inefficient water and nutrient use leaves some boxes unticked with regards to a holistic approach to sustainable and ecologically sound food production within cities.

4.3.6 - Aquaponic food systems

As previously mentioned, aquaponic systems are in many ways the successor to hydroponic systems because they rely on the same equipment and knowledge that hydroponic inquiry developed but with the added entity of aquaculture; the practice of cultivating aquatic creatures in natural or controlled marine environments (Love, 2015). The early pioneers of aquaponic food systems sought the use of plants to maintain water quality in aquaculture practices; enabling the uptake of nitrogen, which is a byproduct of bacterial action. The initial findings relating to this experimental approach reported excellent water quality, fish growth and twice the rate of production for tomatoes against those grown in fields (Lewis, 1978). This brought about the understanding that the symbiosis between fish, bacteria and plants could be utilised for agricultural purposes. This breakthrough led to the very first aquaponic system and gave way to a new line of scientific inquiry. An aquaponic system is similar to a hydroponic system in that it is a recirculating water system that transports water from a reservoir, or in this case a fish tank, to the crops and back again. In the case of an aquaponic system, however, there is an additional element, which is the filtration unit, whereby ammonia from the fish is converted into nitrite and later nitrate through bacterial action, which is then taken up by the crops and removed from the system. Whereas a hydroponic system would simply have a reservoir into which nutrients were added, an aquaponic system requires fish within a fish tank and a filtration unit of some description to make nutrients available to crops.

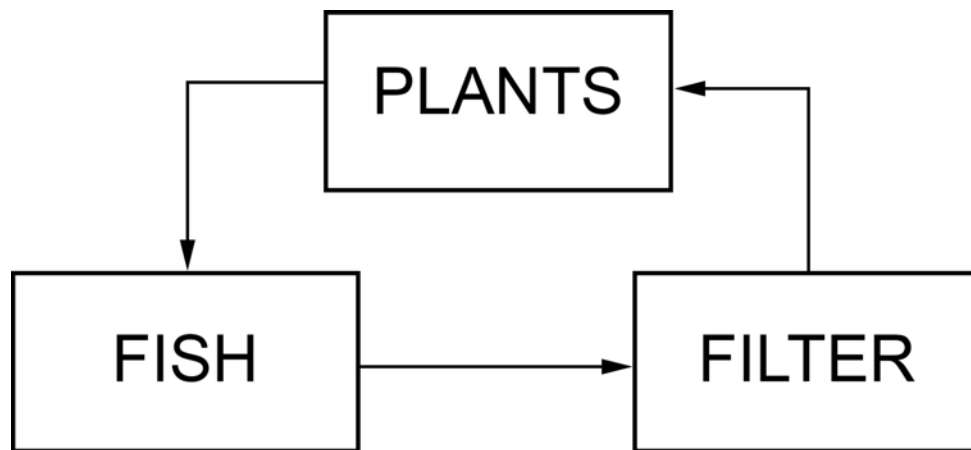


Figure 4.10 - Basic schematic of an aquaponic food system

Due to the way in which nutrients are made available to the crops within an aquaponic system, the cost of agricultural production actually decreases. This is because expensive man-made fertilisers are replaced by rather inexpensive fish food, which, through biological filtration, creates a nutrient solution very similar to those found in hydroponic systems (see figure 4.11). Documented research also estimates that aquaponic food systems are ten to fifteen percent more productive than hydroponic systems (Savidov, 2004) and can produce eight tomato plants and seventeen kilograms of tilapia for the same cost as producing a few tomato plants in a hydroponic system (Bernstein, 2011). This independence from man-made fertilisers also provides an opportunity to produce more natural or even organic crops if organic fish feeds are used. Therefore, aquaponic systems do not only eradicate the demand for mined minerals, but they also provide consumers with the opportunity to buy organic crops and fish. Finally, it has been documented that crops within aquaponic systems are less prone to developing diseases, which may be the result of the presence of some organic matter in the water, creating a stable, ecologically balanced growing environment with a wide diversity of microorganisms, some of which are antagonistic to pathogens that affect the roots of plants (Rakocy, 1999). Aquaponic systems, therefore, provide additional benefits when compared with hydroponic systems or soil-based practices.

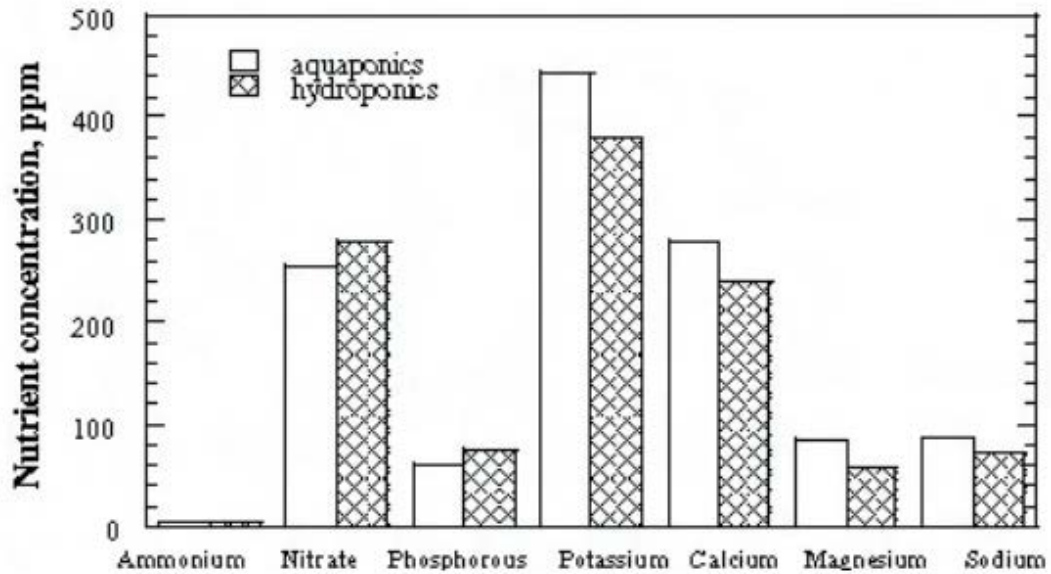


Figure 4.11 - Concentration of macroelements and sodium in aquaponic solution as compared with standard hydroponic mixture (Savidov, 2004)

4.3.7 - Aquaponic nutrient delivery and water use

Aquaponic systems are dependent on the naturally occurring nitrogen cycle to make nutrients available to crops. Through the creation of an ecosystem of fish, bacteria and crops, the system takes waste ammonia (NH_3) produced by the fish as a byproduct of respiration and converts it firstly into nitrite (NO_2) and later into nitrate (NO_3), through the colonisation of *Nitrosomonas* and *Nitrobacter* bacteria within the filtration system, making nitrogen available to the crops. The filtration system typically relies on the use of a highly porous medium, typically an expanded clay pellet or ball, in order to provide a high surface area to maximise the colonisation of the bacteria. This ensures effective filtration of the water supply, which serves two functions; first, ammonia is toxic to fish and if allowed to accumulate within the water supply it can cause harm and even death of the fish stock; secondly, nitrate is an available form of nitrogen - a plant's largest nutrient requirement - which crops can easily take up across the surface of their roots. The fish, bacteria and crops live symbiotically, much as they would within a natural ecosystem. As a result, the level of wellbeing of the fish is increased, bacteria populations thrive, crops grow and the water remains clean. A secondary nutrient source within the system is the solid waste produced by the fish. The conversion of this waste into available nutrients,

however, is a much slower process but can be made available eventually. This is primarily achieved through the separation of the solid waste from the water supply, which can then be broken down through oxygenation, bacterial activity and the possible presence of worms. In some cases, the solid waste needs to be taken out of the system if it is not broken down fast enough because it can restrict the flow of water, interfere with the efficient nutrient absorption of the roots of the crops and promote the growth of anaerobic bacteria, which converts available nitrate and nitrite back into ammonia. If the solid waste does need to be removed from the system, it can be used as a fertiliser within soil-based agricultural systems elsewhere or within gardens if diluted sufficiently.

The use of water within hydroponic systems is relatively low, but within aquaponic systems, water loss is further reduced. This is because the water does not typically need to be changed as long as the system is sized correctly; as a basic rule, this is 0.5kg fish per 0.1m² of growing area (Bernstein, 2011). The primary goal of an aquaponic system, aside from the production of food, is to create a balanced ecosystem that is ecologically self-regulating; that is to say that aside from the addition of food, the removal of solid waste, planting and harvesting, the system will need little intervention. Due to this, the water within an aquaponic system is viewed more as a commodity than simply a carrier of nutrients. The water, therefore, is nurtured to ensure a productive system, and never removed except in cases where the system needs to be cleaned. As a result, water is only lost from the system due to transpiration and evaporation. However, both of these can be mitigated to a certain level, much like that of a hydroponic system, by minimising the contact between the recirculating water and the air, and by trapping and condensing transpiration where possible. In comparison to a hydroponic system, the initial water use of an aquaponic system is much higher due to the necessity of large fish tanks, but once the water is within the system, it stays there; greatly reducing water consumption over the lifetime of the system. A healthy aquaponic system will eventually become acidic over time due to the uptake of hydrogen ions by the plant's roots but this can be remedied through the addition of naturally occurring pH buffers such as eggshells or chalk.

The primary input of many aquaponic systems today is industrially produced fish food, which still creates a dependency on burning fossil fuels. However, aquaponic

systems offer an opportunity to reduce this dependency by tapping into the waste streams of the city. Through the use of waste paper and cardboard from retailers, along with green waste from restaurants, for example, worms can easily be cultivated within vermicomposting systems. The worms in such a system help to break down the biological waste of the city into a usable compost, which can be used in other soil-based growing systems, whilst increasing the worm population. The excess worms can then be fed directly to the fish, which in turn help to produce crops. Waste from any harvests can also be fed back into the vermicomposting system to produce more worms. This closed loop biocyclical thinking will be key to the future prosperity of cities, with regards to both food production and decreasing waste.

4.3.8 - Aquaponic protein production and efficiency

Meat production is an unsustainable method of sustenance due to the inefficient production of calories (Smil, 2002) and the increasing demand for it across the globe. Hence, new methods of protein production are required such as insect farming and increased fish production to decrease the ecological stain created by the demand for meat. In contrast to hydroponic systems, aquaponic systems are able to help address this issue to varying extents through the production of fish biomass as a byproduct of crop production. This byproduct could potentially help ease the strain on the world's current sources of protein and allow some areas of the ocean to be left fallow, allowing fish populations to increase to sustainable levels once more.

In addition to providing an alternative source of protein, fish are also much more efficient at producing protein than other animals bred for consumption. For example, cattle require between five kilograms and twenty kilograms of feed to produce one kilogram of beef dependent on the lifespan of the animal (Meat Promotion Wales, 2006). In contrast, fish only require between 1.4 kilograms to 1.8 kilograms of feed to produce 1 kilogram of meat (FAO, 2014b). Aquaponic lettuces have an even better, albeit indirect, feed conversion rate; only requiring one kilogram of fish feed to indirectly produce 9 kilograms of lettuce biomass (Love, 2015). For the same unit weight to produce one kilogram of beef, an aquaponic system could produce at least 2.7 kilograms of fish meat and forty-five kilograms of lettuces, on a substantially

smaller area of land. This massive increase in protein production in addition to improved conversion efficiencies could increase protein production in urban centres where demand for meat is highest.

4.3.9 - Urban aquaponic food systems summary

In summary, aquaponic systems offer a multitude of benefits in comparison to hydroponic systems. This includes the creation of an ecosystem that is ecologically self-regulating, which minimises human interaction, the reduction in water use, as well as the production of a fish crop in addition to the production of crops. The only inputs to an aquaponic system are fish food and a pinch of calcium to help maintain the water's pH. Although the production of fish food currently relies on the use of fossil fuels there are opportunities to minimise this dependency by tying into the waste streams of cities. This is primarily achievable through the collection of waste paper and cardboard along with vegetable waste to produce worms that can be fed to the fish. Depending on the composition of the fish food, organic crops can also be produced. Aquaponic systems still utilise the growing equipment associated with hydroponic food production and are, therefore, still considered lightweight. However, the need for heavy fish tanks and filtration units creates additional complexity and requires careful planning when considering aquaponic integration within or upon buildings. Much like hydroponic systems, aquaponic systems can still exist under glass or plastic to create a protective environment in which to grow crops. This increases resilience to shock events such as storms, prolonged rainy periods, temperature drops or dry spells, and as a result, can improve food security; that can be further enhanced by the addition of other aquatic species that improve disease control and the resilience of the food system.

Aquaponic systems offer an improved holistic approach to food production in comparison to hydroponic systems when considering water use, human interaction, the production of organic crops and the production of fish. Collectively, these benefits make it a superior method of food production, especially when considering the ability of aquaponic food systems to tap into the organic waste streams of cities. Although aquaponic systems tend to be heavier than hydroponic systems, their benefits compensate for this negative aspect, making them a perfect candidate for urban food production.

4.4 - Soilless growing techniques

There are fundamental differences between hydroponic and aquaponic food systems, particularly relating to how each system make nutrients available to crops. The techniques used by both aquaponic and hydroponic systems to grow the crops themselves, however, are entirely interchangeable. This is primarily because the crops within any given food system are not concerned with how the nutrients have been added or created, they are simply interested in utilising these nutrients for growth. Therefore, once the nutrients are available within the system, both hydroponic and aquaponic systems are purely soilless food systems and can utilise the same methods of crop production. Surprisingly, many of these methods are very simple and easy to construct, but also very effective. Collectively, there are four recognised techniques of growing crops within soilless systems. These include, nutrient film technique, also known as 'NFT', which utilises between a few millimetres and a centimetre of water running down a plastic channel, within which the root of the crops are placed; water culture, otherwise known as a raft system, which suspends the roots of crops in a large body of nutrient-rich water through the use of a buoyant material or 'raft'; aeroponic systems, which continually or periodically spray the roots of the crops from below with a nutrient-rich mist; and media beds, which act as an inert substrate that can either be continually flooded and drained or simply allowed for a nutrient-rich solution to trickle through it continually. Further details of these individual techniques of crop production are given in the proceeding sections, along with a few examples to better clarify the differences between them.

4.4.1 - Nutrient film technique (NFT)

Nutrient film technique - also referred to as 'nutrient flow technique' and commonly shortened to the acronym 'NFT' - is one of the best-known methods of crop production within soilless systems. NFT is a soilless growing technique in which crops are grown with their roots contained within a plastic channel, into which, a very thin layer of nutrient-rich water is pumped.

This technique was pioneered in 1965 at the Glasshouse Crops Research Institute in Littlehampton, England. The very first NFT system, which was a hydroponic

system, was comprised of a catchment trench along the middle of a greenhouse, with 'layflat' polythene troughs - which can be thought of as unsupported polythene tubes - that were placed perpendicular to the trench on inclined ground to promote the movement of water. The water from the trench was then pumped to the top of each polythene trough and allowed to flow freely back to the trench, where the process would start again. As such the term 'nutrient film technique' originated to stress that the depth of liquid flowing past the roots of the crops was so thin that it could be considered a 'film' to ensure that sufficient oxygen would be supplied to the plant roots (Cooper, 1979).

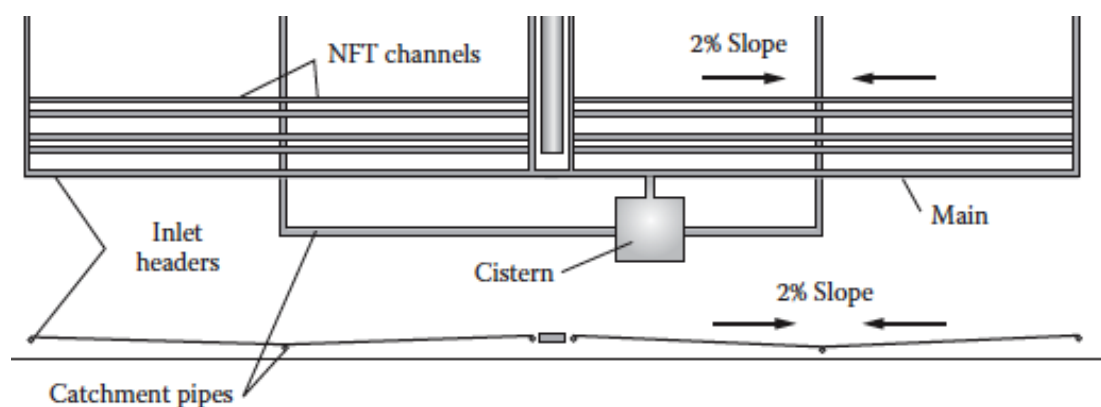


Figure 4.12 - Typical layout of an NFT system

By the end of the 1970s, NFT systems were either in commercial use or being tested in sixty-eight countries (Cooper, 1976). By 1991, the UK was growing forty hectares of tomatoes through the use of NFT systems and during the 1990s mineral wool was introduced as a medium to support the crops, which soon became the most accepted method of growing vine crops such as peppers, cucumbers and tomatoes. Today, the method remains very much the same, only with the use of plastic growing channels that are elevated off the ground to improve working conditions and productivity (see figure 4.13).



Figure 4.13 - Modern NFT system

A variation of this arrangement was first experimented with when Dr. Schippers from the Long Island Horticultural Research Laboratory of Cornell University developed what he referred to as 'nutrient flow technique'; as opposed to 'nutrient film technique'. In an effort to maximise the vertical space of a greenhouse Dr Schippers experimented with vertical pipes, down which the nutrient solution dripped, moistening and feeding the plants, such as those seen in Epcot Disney World Resort (see figure 4.14). The working hypothesis of this development was that by increasing the number of plants that can be grown in any given area, the cost of production per crop would decrease (Kubiac, 2000).



Figure 4.14 - Vertical NFT system at Epcot, Florida

Dr Schippers would later go on to develop other, more efficient vertical systems such as the 'cascade' system as well as an A-frame variant (Schippers, 1977). These systems are especially successful in producing low leaf crops such as lettuce, radish and peas. The cascade system (see figure 4.15) relied on the vertical stacking of up to eight slightly inclined growing channels, where the nutrient solution was pumped to the high end of the uppermost pipe, exiting at the low end of that pipe and into the high end of the next one, and so on, until the water reached the reservoir from where it was pumped. However, the A-frame variant of this design, where the frames had an east-west orientation, would make more efficient use of greenhouse space and minimise overshadowing (see figure 4.16). Both of these arrangements were found to be suitable for growing lettuces, strawberries, spinach and herbs.

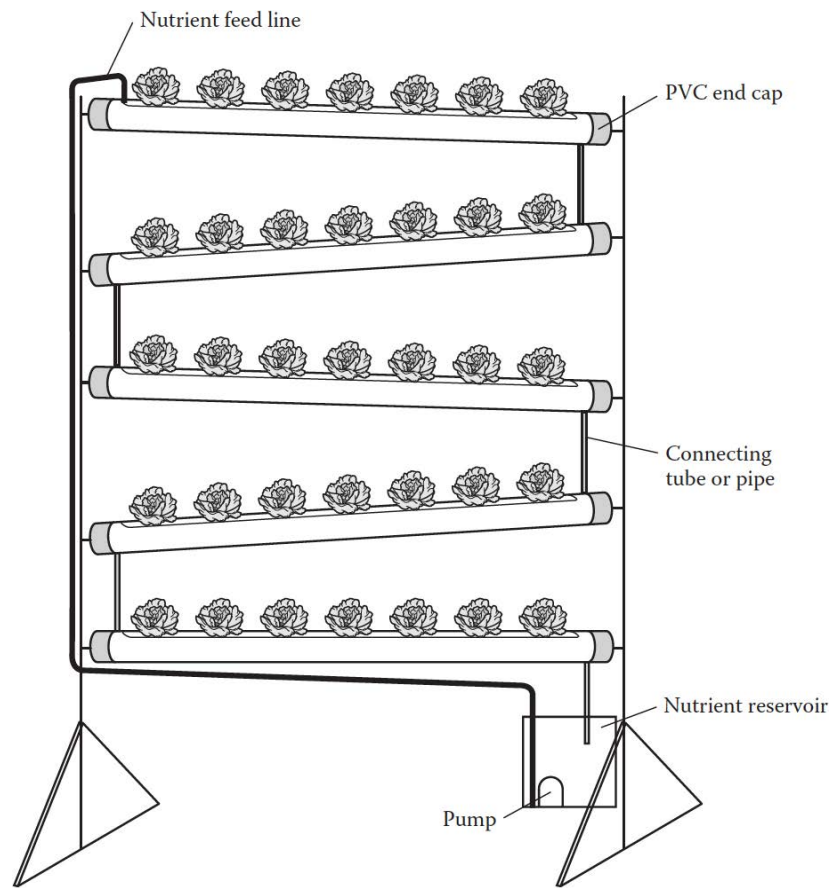


Figure 4.15 - Cascade NFT growing system



Figure 4.16 - Modern A-frame cascade NFT growing system

Ultimately, these are simply variations in the arrangement of NFT channels, but it identifies the flexibility of the growing technique to produce food on either horizontal or vertical planes, which becomes very useful when considering rooftop and facade-based food systems. Such systems are also very lightweight when compared with soil-based systems; consisting of a few crops, a few millimetres of water and a plastic tray. There are a couple of universal rules that should be noted when designing NFT systems, however. Firstly, the growing channels should be no longer than fifteen metres. This ensures that there is still a sufficient concentration of nutrients within the water by the time it reaches the final crop along a long NFT channel. Secondly, there should be a minimum slope of two percent (7.2 degrees) to provide the adequate flow of nutrients. NFT systems are suitable for quick growing short-term crops because long-term crops with larger root systems block the channels, causing reduced flow of the nutrient solution and a resultant lack of oxygen, leading to blossom-end rot on fruit and eventual death of the plant. The maximum practical length - i.e. the length that can be carried by two people while planted - of any growing channel should not typically extend 4.6 metres. Additionally, small fins in the bottom of the growing channel will allow a less restricted path for the nutrient solution and the use of a cover on top of the channel, with holes cut for plants, will help minimise evaporation. Most leafy plants are spaced at twenty-centimetre centres, with channels spaced between fifteen to eighteen centimetres apart; centre to centre. Smaller herbs can be spaced fifteen centimetres apart with the growing channels also fifteen centimetres apart (Resh, 2013).

4.4.2 - Water culture

Water culture, also known as deep water culture or raft culture, suspends plant roots in nutrient-rich water approximately three hundred millimetres in depth, while the crown of the plant is supported by a buoyant 'raft', which doubles as an insulating cover. This form of crop production was developed by Dr Jensen of the University of Arizona between 1981 and 1982 where he developed a raceway prototype; i.e. a thin and long pool of water (see figure 4.17). Within a water culture system, the nutrient-rich water is pumped into the beginning of the raceway, where the water very gradually moves underneath the rafts, until it reaches the end of the raceway and returns to the reservoir. Within the small greenhouses of today - i.e. less than 0.5 hectares - raceway waterbeds are still the most common form of raft system.

This is primarily because of ease of maintenance and handling, but also due to increased resilience of the system if one raceway were to fail. These raceways are typically 14 centimetres deep, with an inside width of 1.25 metres and a length that is ultimately determined by the length of the greenhouse or polytunnel (Kratky, et al., 2008).



Figure 4.17 - Example of a water culture raceway growing system

The use of a buoyant cover to support the crops also allows the water to be heated, if required, resulting in reduced heat loss, especially if the walls are also insulated. This concept can also be reversed; i.e. keeping the body of water cooler in hot climates. This would not be achievable in an NFT system, for example, because the heat loss down the length of a growing channel would be too severe. The additional benefit with a raft system, is that when crops are ready to be harvested, they are simply taken from one end of the raceway, allowing space for newly transplanted crops to be placed at the beginning of the raceway, effectively producing a conveyor belt of production, which makes the system very space efficient. Again, much like the crops produced in NFT systems, the production of low-profile crops are

recommended (Resh, 2013). Another method of production within smaller greenhouses is to construct waterbeds based upon the standard size of polystyrene sheets, or any sheets for that matter, which is typically 1.2 metres by 2.4 metres. Cutting them in half allows a 1.2-metre grid to be utilised to fit any given space. The sheets could be cut down again into sixty-centimetre squares to give a greater level of flexibility, if required. This makes them much easier to handle, especially if the systems is only operated by a single person.



Figure 4.18 - Example of a small-scale water culture system

In summary, water culture food systems offer some additional benefits when compared with the other production techniques contained within this chapter. The main advantage of water culture systems, regarding resource use, is the ability to insulate a large body of water that can be heated or kept cool to improve productivity. This is something that other techniques cannot offer. Additionally, the ability to move the plants down the system as they mature, until they are harvested at the end allows improved efficiency of workers and increases the efficiency of crop production, because less space is needed to allow workers to access the system.

However, in the realms of urban agriculture, water culture suffers from one undeniable flaw, which is weight. Much like soil-based systems, such large bodies of water are difficult to support safely whether upon internal floor plates of roof structures of existing buildings. Based on the minimum loadings previously discussed, roof structures would only be able to support a maximum of 150 millimetres of water, whereas internal floor plates would only be able to support a maximum of 250 millimetres of water. In reality, these depths of water would diminish greatly when considering the weight of the additional equipment required, and the movement of the people around the system. In most cases, this restricts the safe use of water culture systems to ground-level production, whether within a building or on open land, to ensure the safety of those working or living within existing buildings.

4.4.3 - Aeroponic systems

Aeroponic systems are a method of food production that makes use of a nutrient-rich mist that is sprayed directly onto the roots of the plants from below. The crown of the plant is supported by a strong outer shell, that helps form a watertight seal around the humid and misty root zone. This practice is widely used in laboratory studies but is not used as commonly as other techniques on a commercial scale. There are several forms that aeroponics systems can employ, but ultimately, the practice depends on the production of a watertight box into which plants can be placed and supported. High-pressure nozzles are located under each plant to spray the root sufficiently with a nutrient-rich mist, which ensures the healthy development of the plant.



Figure 4.19 - Example of an a-frame aeroponic food system

In addition to the box structures typically utilised for aeroponic systems, there are also suspended vertical systems, which look identical to those seen previously with regards to NFT systems. This method of aeroponic production simply places an inner tube down the middle of the outer tube, which then sprays the roots of each crop (see figure 4.20). The main advantage of aeroponic systems is that water use and energy use can be extremely low. Because the outer shell of an aeroponic system is watertight, the only water loss is through transpiration, and as long as the relative humidity within the box is kept high enough, the roots of the plants only need to be sprayed periodically, reducing energy use. The fact that the roots are suspended in a mist means oxygenation of the root zone is very high, leading to the production of healthy plants.



Figure 4.20 - Vertical aeroponic growing system

4.4.4 - Media beds

The final recognised technique of hydroponic or aquaponic food production is through the use of 'media beds'. Media beds are very different to the three previously mentioned techniques of food production because it is dependent on the use of an inert substrate to grow food. The use of a substrate offers many of the advantages of soil-based food production, such as root anchorage, but without the additional weight. The substrate must provide good water retention as well as good drainage to ensure that the crops receive sufficient contact with the nutrient solution, as well as ensuring sufficient root oxygenation. In addition to this, the media must not decompose and must not alter the chemical composition of the nutrient solution. The need for good water retention and good drainage means that fine materials such as sand are avoided, in preference to other materials with larger particle sizes and better porosity. There are a multitude of different mediums that can be used within media beds to grow food, which can range from heavy gravels to lightweight volcanic glass. The beds can also be any size, but much like soil-based raised beds, they need to be a minimum of thirty centimetres deep, to ensure a sufficient zone for root development. The benefits of growing food in this way are that the media

utilised within the food system can perform additional tasks with regards to aquaponic growing. For example, the media beds can also be utilised as the biological filter and become the home of the nitrifying bacteria due to the excellent oxygenation of the media as well as the constant supply of water. Typically, media beds use hydroton (see figure 4.21), which is an expanded clay ball, as the substrate within the grow beds because this provides a very high surface area due to the porosity of the material, as well as sufficient anchorage without being too heavy.



Figure 4.21 - Media bed growing system

There are two primary methods of delivering the nutrient solution to the roots of crops with a media bed food system. The first method is referred to as an 'ebb and flow' system (see figure 4.22), which periodically floods the media bed and then drains it through the use of either a timer or a syphon. This ensures that each and every particle within the media bed is supplied with nutrient solution. This method can be run continuously, or periodically to achieve similar results. The second method is a 'gravity based trickle' system (see figure 4.23), which provides multiple water outlets at the surface of the bed where nutrient rich solution is continuously trickled through the substrate. This is a much simpler method of nutrient delivery but

it is not as effective because it can be difficult to ensure that every particle is sufficiently moistened. Ultimately, media beds offer many benefits in comparison to the other growing techniques. This includes the anchorage of larger plants allowing the production of root veg and squashes, for example, as well as acting as a biological filter for aquaponic systems. However, media beds are much heavier, when compared with NFT systems, for example.

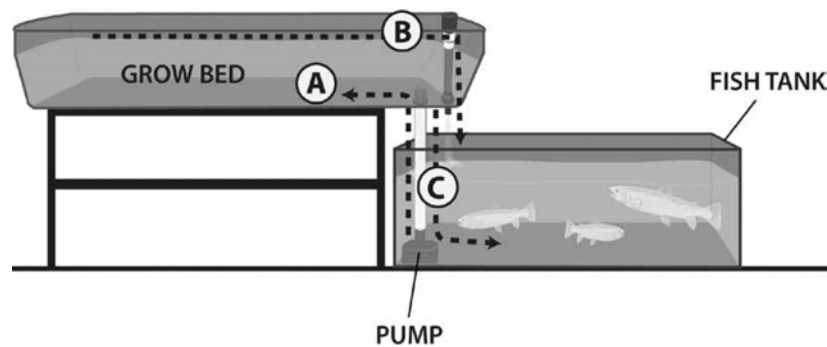


Figure 4.22 - Ebb and flow system

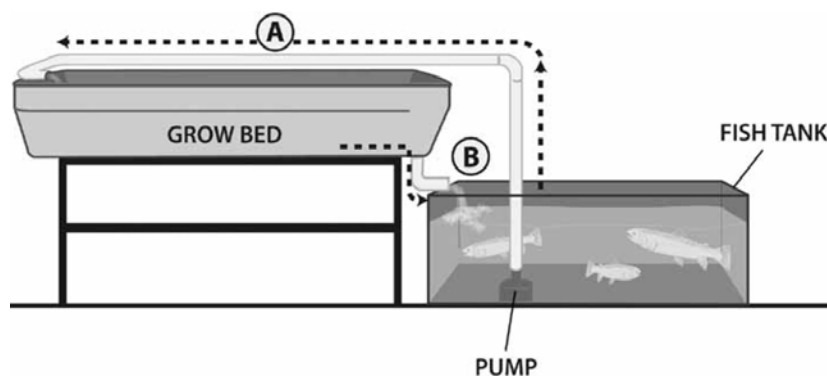


Figure 4.23 - Gravity based trickle system

4.4.5 - Plant factories with artificial light

Plant factories with artificial lighting, otherwise known as PFAL systems, are crop production facilities, which depend on the provision of a thermally insulated, hermetically sealed and sterile structure to grow food (see figure 4.24.). Plant factories are typically water culture hydroponic systems, which utilise very shallow trays rather than deep bodies of water, to achieve high-density food production. Plant factories do not offer any additional nutrient delivery methods or growing techniques than those previously mentioned, but they do form a distinct typology of

food production, which is why they have been included in this analysis of technical food systems. PFAL systems consist of multiple shelves of food production with artificial lighting above each shelf to promote growth. The basic principle of a plant factory, much like the early NFT systems pioneered by Dr Schippers, is that they make better use of vertical space to maximise the productivity of technical food systems. Stacking shelves upon shelves of food production can improve the annual sales volumes of some systems per unit land area, depending on what crops are being produced, by up to one hundred times when compared with open field production (Kozai, et al., 2016).



Figure 4.24 - Example of a plant factory

These systems, however, are dependent on other necessary equipment to grow food such as air conditioning units, air circulation fans, carbon dioxide supply units, nutrient solution supply units, and environmental control units (Kozai, 2013). Although the development of LED lamps for food production has reduced the energy use of these systems over recent years, the air handling units and environmental controls associated with the production of crops within PFAL systems still rely on high energy use to perform. The need for artificial lighting and air handling units also results in high initial capital investment, when compared with other technical food

systems. However, the density of production documented within these systems may allow these costs to be recouped quicker than the costs associated with lower-density food systems.

Through the use of PFAL systems, high-quality pesticide-free crops can be produced all year round, regardless of external climates, due to the optimal control of the environment and nutrient uptake. Leaf vegetables produced in plant factories are safe to eat immediately after harvesting, requiring no further washing before cooking or processing, due to the lack of use of pesticides and stringent hygiene standards. The shelf life of these vegetables after harvest is also doubled compared to those produced in a greenhouse because the bacterial load is lower. The crops suitable for growth within PFAL systems should be smaller than thirty centimetres tall when full-sized, to maximise production vertically, and should grow well at relatively low light intensities and should thrive when in close proximity to other crops. Hence, staple foods such as potatoes or wheat are not suitable for PFAL production (Kozai, 2013). Smaller PFAL systems can also be utilised specifically for the growth of seedlings, which can be grown at extremely high densities and later transplanted into other, less energy dependent food systems.

In summary, plant factories are high-density hydroponic systems which aim to control all the environmental aspects that affect crop growth; such as air composition, temperature, ventilation, humidity, nutrient solution and light intensity. Much like hydroponic systems, PFAL systems are reliant on the production of mined minerals for crop growth in most cases and as a result are still fossil-fuel dependent. As with any hydroponic system, the nutrient solution with a PFAL system will need replacing periodically as the composition of the solution changes throughout the development of the crops, and close attention will be required to ensure a stable system is achieved. Although the water within the system needs to be periodically replaced, PFAL systems still utilise much less water than irrigated soil-based agriculture, and the addition of the hermetically sealed box makes it even easier to control evaporation and transpiration recovery. Due to the multi-level structure of PFAL systems, their weight is greatly increased, although due to the use of artificial lighting there is no need to place such a system on the roof of an existing building, where natural light is abundant. Instead, these systems can be placed within an existing building where the structure is much stronger and capable of supporting

almost twice as much load. This is of particular interest in the presence of pitched roofs where the integration of typical hydroponic or aquaponic systems would be highly complicated and possibly unsafe at roof-level. The largest benefit of utilising a PFAL system is the sterile environment that is created, which eradicates the need for pesticides and herbicides to protect crops. Although this is a positive attribute of PFAL systems, it could also lead to the loss of an entire crop if pathogens were to enter the growing facility. Ultimately, PFAL systems can significantly increase food production per unit of land through the stacking of crops, but their additional use of energy and additional weight makes them a less holistic approach to urban food production when compared with aquaponic food systems.

4.4.6 - Summary of soilless growing techniques

The different nutrient delivery systems - i.e. hydroponic and aquaponic techniques - both have positive and negative aspects with regards to urban integration. For example, hydroponic systems are much lighter but require increased human interaction, whereas aquaponic systems are heavier, due to the fish tanks and filtration units, but become ecologically self-regulating over time, minimising human intervention, as well as producing a fish harvest as a byproduct. The different technological approaches to the production of crops also have varying positive and negative aspects, such as that a water culture system is heavy but can be more appropriately heated, whereas the lightweight nature of an NFT system makes it impossible to heat successfully. The integration of technological food systems, therefore, is not a 'one size fits all' approach and requires an understanding of where each system would be most appropriately placed within an existing building.

The best way to collate this information is to create a taxonomy of both the nutrient delivery systems and the growing techniques noted previously, to identify their strengths and weaknesses, as well as their possible placement within an existing building; such as the basement level, ground level, intermediate floor, and rooftop. This will be conducted for the nutrient delivery systems initially (table 4.8), then the growing techniques (table 4.9), before culminating in the possible combinations of nutrient delivery systems and growing techniques at basement level, ground level, intermediate floor, and rooftop (table 4.10). It should be noted that the locations of these possible combinations within an existing building are driven by the minimum

imposed loads of floors and roofs within the UK, which have been discussed previously. Due to this, the locations of such nutrient delivery systems and growing techniques within an existing building are considered typical and not ubiquitous.

Table 4.8 - Positive and negative aspects of the two primary nutrient delivery systems and their possible placement within an existing building

Nutrient Delivery	Positive	Negative	Typical Placement
Hydroponic	Lightweight Low maintenance	Requires periodic intervention Reliant on mined minerals	Basement Ground floor Intermediate floor Rooftop
Aquaponic	Creates ecosystem Ecologically self-regulating Fish food is main input Minimal amounts of calcium required Fish harvest as a byproduct Capable of producing organic food Can tie into waste streams of the city	Fish tanks and filtration unit can be heavy Requires deep cleaning periodically	Basement Ground floor

Table 4.9 - Positive and negative aspects of the five primary growing techniques and their possible placement within an existing building

Growing Technique	Positive	Negative	Typical Placement
NFT	Very lightweight Easily constructed	Cannot be heated Low-crops only	Anywhere
Water culture	Can be heated Can be cooled Conveyor belt-like production	Heavy Requires more nutrients to maintain large body of water Low-crops only	Ground floor Basement
Aeroponics	Lightweight Low energy requirements	More complex construction More complex equipment	Anywhere
Media bed	Provides structural support to larger crops Can also be the biological filter for an aquaponic system	Midweight Requires cleaning Difficult to clean without disturbing crops	Internal floor Ground floor Basement
Plant factory	Very high density production Easily handled Easily cleaned No chemicals	Midweight Dependent on: - artificial light - air handling units - environmental control Largest energy consumption of noted techniques	Internal floor Ground floor Basement

Table 4.10 - Typical locations of nutrient delivery systems and growing techniques within existing buildings

Location	Nutrient Delivery System	Growing Technique
Rooftop	Hydroponic	Aeroponic Nutrient Film Technique
Intermediate Floor	Hydroponic	Aeroponic Nutrient Film Technique Media Beds Plant Factory
Ground Level	Hydroponic Aquaponic	Aeroponic Nutrient Film Technique Media Beds Plant Factory Water Culture
Basement	Hydroponic Aquaponic	Aeroponic Nutrient Film Technique Media Beds Plant Factory Water Culture

4.5 - Examples of urban technical food systems

Based on the information contained in this chapter, it can be seen that there is a multitude of different approaches to growing food within or upon buildings in high-density cities. Through the creation of the preceding taxonomies and the concluding typical locations of nutrient delivery systems and growing techniques within existing buildings, three distinct typologies come into focus. These include ground-level aquaponic systems, intermediate floor plant factories and rooftop hydroponic systems. These typologies are driven by the respective weights of

hydroponic, aquaponic and PFAL systems, and the likelihood of their safe and effective integration within existing buildings at each given level. For example, although hydroponic systems can typically exist at any building level, they would be best placed on the roof, where neither aquaponic systems nor plant factories could be safely supported by expected roof structures. Aquaponic systems would be, in most cases, restricted to the ground-level or basement of an existing building due to the weight of large fish tanks and filtration units, and plant factories due to their lighter weight - when compared with aquaponic systems - would be best placed on intermediate floors, in between the hydroponic and aquaponic systems, where light levels are reduced. These typologies, however, are not exhaustive and there is no reason why a hydroponic system could not exist in the basement of a building, or the nutrient-rich water from an aquaponic system could not be pumped to other floors within the building. Nevertheless, within a high-density city where all three growing options are utilised due to their different strengths, these typologies would serve as a good starting point for any strategy of integration.

Examples of these systems are shown in the proceeding sections to draw attention to the urban food systems that are already in effect. It should be noted that no large-scale examples of technological food systems within the intermediate floors of existing buildings are known to this thesis, so the examples presented of plant factories are all ground-based. However, this does not detract from the fact that internal floors would be a suitable location for plant factories due to the reduced access to natural light, and the ability of internal floors to carry additional weight.

4.5.1 - Ground based systems - Aquaponic

The Plant - Chicago - Aquaponic Water Culture System



Figure 4.25 - Exterior of The Plant, Chicago



Figure 4.26 - Interior of The Plant, Chicago

Urban Organics - Minnesota - Aquaponic Water Culture System



Figure 4.27 - Exterior of Urban Organics, Minnesota



Figure 4.28 - Fish tanks at Urban Organics, Minnesota



Figure 4.29 - Water culture system at Urban Organics, Minnesota

Farm:shop - London - Aquaponic NFT/Water Culture system



Figure 4.30 - Exterior of FARM:shop, UK



Figure 4.31 - Interior of FARM:shop, UK

4.5.2 - Internal floors - Plant factory

Growing Underground - London - Hydroponic Water Culture System



Figure 4.32 - Water culture system at Growing Underground, UK



Figure 4.33 - Salad crops at Growing Underground, UK

Freight Farms - Various Locations - Hydroponic



Figure 4.34 - Exterior of Freight Farms, UK



Figure 4.35 - Interior of Freight Farms, UK

Sanriku Fukko Plant Factory - Sanriku Fukko National Park - Hydroponic water culture

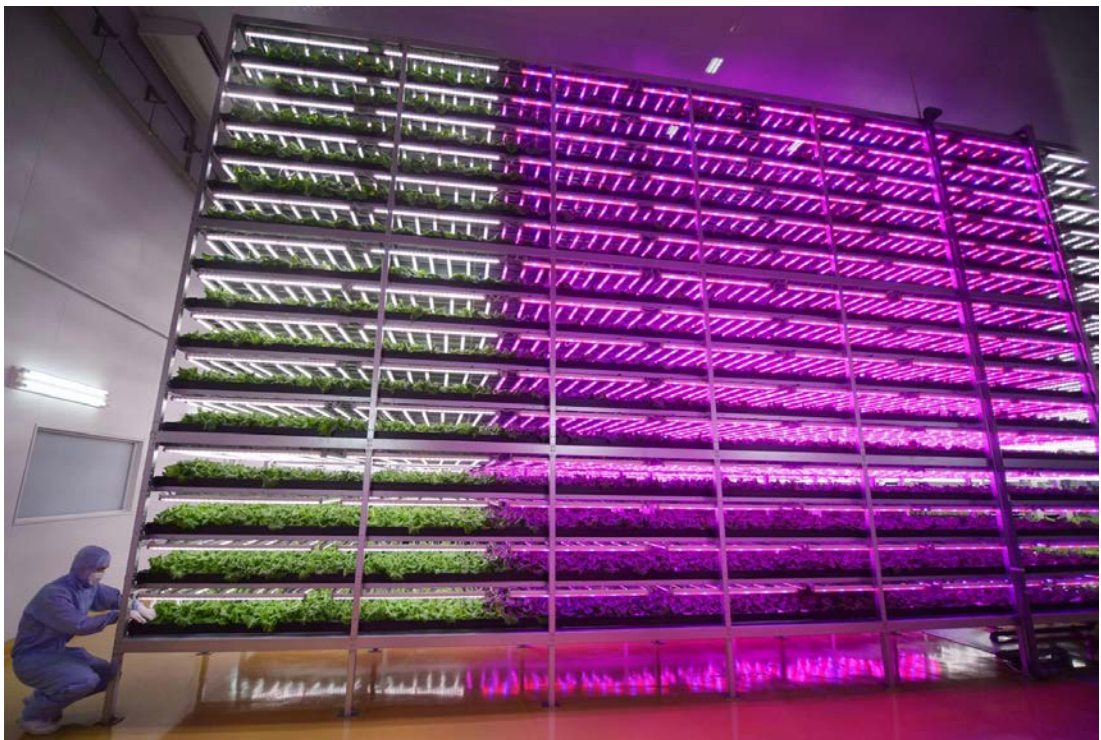


Figure 4.36 - Water culture system at Sanriku Fukko Plant Factory, Japan



Figure 4.37 - Worker with produce at Sanriku Fukko Plant Factory, Japan

4.5.3 - Roof based systems - Hydroponic

Sky Vegetables - New York - Hydroponic NFT System



Figure 4.38 - Rooftop greenhouses at Sky Vegetables, New York



Figure 4.39 - Interior of rooftop greenhouses at Sky Vegetables, New York

Lufa farms - Montreal - Hydroponic NFT System



Figure 4.40 - Rooftop greenhouses at Lufa Farms, Montreal



Figure 4.41 - Interior of rooftop greenhouses at Lufa Farms, Montreal

Bell Book & Candle Restaurant - New York - Hydroponic Aeroponic System



Figure 4.42 - Vertical growing at Bell Book & Candle Restaurant, New York



Figure 4.43 - Strawberry production at Bell Book & Candle Restaurant, New York

4.6 - Summary and conclusions of urban food production

Although urban soils are contaminated - in some cases well above safe levels - and access to available space within high-density cities at ground-level is highly competitive, there are many different methods of growing food within urban environments that ensure food safety standards are upheld, whilst utilising the untapped potential of forgotten urban spaces such as rooftops, unoccupied internal floors, basements and tunnels. Technical food systems in their many different shapes and sizes provide these opportunities, which not only utilise a fraction of the water of traditional irrigated soil-based systems but also allow food to be grown where demand is highest; i.e. within cities. As a result, this can lead to a reduction in the distance food travels from production to consumption, a reduced need to burn fossil fuels, and a reduced demand for packaging, refrigeration and freezing.

The placement of these novel technical food systems within urban environments ultimately depends on their individual strengths and weaknesses. For example, it

would not be recommended to place heavy water culture systems or the large fish tanks of an aquaponic system on the roof of an existing building due to the possibility of structural damage or structural failure, unless otherwise agreed to by an accredited structural engineer. Neither would it make sense to place an NFT system in the basement of a building, when more crops could be produced through the integration of a plant factory. Hydroponic systems offer great weight savings at roof level, which opens up a plethora of sites for urban agriculture without compromising the structural integration of existing buildings, and aquaponic systems offer the opportunity to create ecologically self-regulating ecosystems that can plug into, and make good use of, the waste streams of the city; helping to develop circular economies as a result.

The future of urban food production, therefore, is dependent on the successful interface between the technology - i.e. the hardware - and the living systems that grow food - i.e. the software - as well as the custodians that both passively and directly engage with these two entities - i.e. urban populations. Cities have vast surface areas upon which crops could be grown and technical food systems in most cases can allow this to occur, which would simultaneously decrease the ecological footprint of cities whilst improving food security to varying degrees depending upon the scale, redundancy and provision of protection from weather and climate change.

Today, the scale at which technological food systems operate within high-density cities is relatively small and their effects on a large scale are unknown. For example, it is not currently known how many crops a city-wide urban food initiative could produce within a high-density city, neither is it known how many jobs this would create and how such a large scale agricultural intervention would affect urban populations. The majority of today's cities are comprised of historic and dated buildings; some of which are in much need of repair. In order for urban agriculture to have any chance of making a measurable impact on UK food security, these existing buildings, regardless of age and condition, will have to be able to accept the safe and beneficial integration of technical food systems; through the design and development of appropriate nutrient delivery systems and growing techniques that are capable of meeting a multitude of constraints.

In order to assess the applicability of large-scale urban agriculture within high-density cities, there needs to be much more experimentation conducted with regards to the integration of technical food systems within existing buildings. It is the existing urban context that offers both opportunities and constraints for agricultural integration but currently, there is very little communicable knowledge regarding the difficulties faced when integrating technical food systems within existing buildings and that is what will be addressed in the next chapter.

5.0

EXPERIMENTS

5.0 // EXPERIMENTS //

In the previous chapter, the different methods of food production that are applicable to the urban context were identified, which included both soil-based and soilless food systems. Although soil-based agriculture is a tried and tested method, it may not be the best form of agriculture within cities due to native soil contamination, lack of open space, and inherent weight, which make it difficult to safely add to existing buildings. Technical food systems, on the other hand, offer an opportunity to grow food within or upon buildings, due to their reduced weight, while minimising water use and offering the opportunity to tie into at least some of the waste streams of the city. The following chapter aims to identify and communicate some of the predominant technical challenges that face the integration of technical food systems within existing buildings through the design, construction and commissioning of a large-scale aquaponic system, within an old industrial building in Salford, England.

5.1 - The opportunity to experiment

At the beginning of 2012, Queen's University Belfast - to be referred to as QUB from hereon - was approached by the Manchester International Festival - to be known as MIF from hereon - to design and construct a working urban farm for the Manchester International Festival 2013, which would run between the 5th and 21st of July 2013. The festival is a celebration of socially engaging and cultural arts, priding itself on providing a stage for the presentation of original work. The urban farm would form part of 'The Biospheric Project', which would also include mushroom production and the development of a socially inclusive urban forest garden. The location for this urban farm would be within an old factory building, known as Irwell House, on the banks of the River Irwell in Salford, England. Irwell House was the home of the Biospheric Foundation; an urban 'living lab' that allowed universities and individuals the opportunity to prototype and test urban ecological practices within a dilapidated building that could be adapted to suit almost any experiment. It is this link with the Biospheric Foundation that led to the creation of the Biospheric Project. Photos taken at the very beginning of this process are shown on the proceeding pages.



Figure 5.1 - Irwell House and the proposed site of the forest garden



Figure 5.2 - The south-facing rear elevation of Irwell House



Figure 5.3 - Second floor of Irwell House looking north west



Figure 5.4 - The roof of Irwell House looking south east

5.1.1 - Consideration of different food systems

As mentioned in the previous chapter, traditional soil-based techniques are not typically the best method of urban food production in high-density cities due to native soil contamination, lack of available space at ground-level and inherent weight, which makes them difficult to integrate within or upon existing buildings. Due to the context of the Biospheric Project, the urban farm would, therefore, either have to be a hydroponic or aquaponic system, which both offer additional benefits when compared with traditional soil-based practices. In the previous chapter, the positive and negative aspects of hydroponic and aquaponic systems were identified, along with the positive and negative aspects of the five primary growing techniques. This allowed conclusions to be drawn as to where each element of a technical food system could be located within an existing building. The conclusions of this analysis determined that hydroponic systems could be located on every building level including the roof, and aquaponic systems would be safest when located at ground or basement-level due to their additional weight. It was also concluded that aeroponic and NFT growing techniques could be located throughout existing buildings including the roof, media beds and plant factories could be located on every level aside from the roof, and water culture systems could be located on the ground level or basement level due to their weight.

Although the primary aim of the project was to grow food and determine the technical challenges associated with integrating a technical food system within an existing building, it was also viewed as an opportunity to experiment with ecological urbanism. Therefore, the system chosen to exist within the building would need to grow food as well as reduce the need for resources, such as water and energy, and be capable of utilising waste flows from the surrounding city in one form or another. Therefore, it was decided that the development of an aquaponic system within the building would best address the aims of the project due to the benefits aquaponic systems provide, such as the creation of a self-regulating ecosystem, reduced water use, decreased human interaction, redundancy of man-made minerals, the production of a fish harvest, and the possibility to tap into the waste streams of the city; which are all desirable qualities when developing sustainable and biocyclical urban strategies.

5.1.2 - Initial concept design

In order to be given the opportunity to conduct the research required for this thesis and to be officially appointed by MIF to carry out the work for the festival, an initial concept design was needed to capture the minds of the organising committee. At the beginning of this process, very little was known regarding how a technological food system might be integrated into an existing building. Hence, some of the ideas contained within this initial design phase may seem contradictory to the points made in the previous chapter. Therefore, this initial conceptual design is not to be taken too literally as it simply set out the ambitions of QUB in order to explain to the festival what might be possible within this old industrial building.



Figure 5.5 - Initial concept design for the Biospheric Project

The initial concept design envisioned an aquaponic system on the first floor, public engagement space on the top floor and raised bed growing on the roof. Unfortunately, the ground floor of Irwell House was occupied by two automotive garages and was therefore inaccessible and unusable for the development of the project. Although initially this was seen as a drawback to the future development of the project and the integration of a heavy aquaponic system, it was later viewed as an opportunity to explore if it was possible to integrate such a heavy technical food system above ground-level.



Figure 5.6 - Initial concept design for roof garden

The land adjacent to the building would be utilised for the agroforestry element of the Biospheric Project, which would create a space for both public engagement and food production. The initial concept design for the urban farm was presented to the organisers towards the middle of 2012 and discussed in terms of 'experimentation', 'knowledge creation', 'exhibition', 'community hub' and 'improving food access', which helped formulate the initial brief for the project. Hence, the project not only needed to operate as an urban farm but also an exhibition as well as a community resource. The long-term goal of the project would be for the community to later run and maintain the system upon the departure of QUB from the project; creating a handful of jobs and providing healthy food in the area of Blackfriars, which is known for its high level of deprivation. The project was given the green light towards the end of 2012 and QUB was appointed to deliver the technical food system as part of the Biospheric Project. The project took its first steps to completion in October 2012 when the design team, noted below, started on site.



Figure 5.7 - The design team from left to right - Andrew Jenkins (lead technical designer), Natalie Hall (lead biocyclical designer), Prof. Greg Keeffe (project manager)

5.2 - Small-scale experimentation

Due to the lack of communicable knowledge relating to both ground-level and above ground-level technical food systems within existing buildings - as stated previously within this thesis - it was imperative to start designing and testing aquaponic systems as soon as possible; in order to gain the relevant knowledge needed to design and construct the larger system that could not be obtained any other way. The decision was made early on that a small-scale aquaponic prototype should be built to gain first-hand experience of designing, constructing and running an aquaponic system. Unlike hydroponic systems, which has decades of rigorous scientific research to help guide the design of new systems, aquaponic systems are based more on 'rules of thumb' rather than exact specifications. This is primarily due to the self-regulating nature of aquaponic systems which allows for greater tolerances; the basic principle is that if there are enough fish, enough bacteria, and enough plants, then the system will work as expected. Although this can be seen as yet another advantage of aquaponic food systems, it does create problems when designing such systems without prior knowledge. This is due to the fact that securing reliable information can be troublesome. Therefore, the strategy for the initial small-scale aquaponic system would be to keep the design as simple as possible by only utilising a few fish in a large tank - so as to avoid any chemical imbalances that might harm the fish - and to utilise shallow media beds that doubled up as both filtration and areas of growth - minimising the number of elements that needed to be designed, constructed and that ultimately, could fail. As a result, the small-scale aquaponic systems would only require a fish tank and media beds grow crops.

5.2.1 - Design

The design of the small-scale aquaponic system was developed based on what materials were available to hand to minimise expenditure; allowing a larger sum of money to be available to construct the larger aquaponic food system. Therefore, the small-scale aquaponic system was designed around the use of a large fish tank that was already on site when QUB started on site.



Figure 5.8 - Small-scale aquaponic fish tank

The initial design ethos was to place a gravity-based trickle system above the tank as this would only require a pump on a timer, but it quickly became apparent that it would be difficult to distribute the water effectively across the grow bed. This type of arrangement could also lead to issues relating to overflowing if the holes in the base of the grow beds became blocked. Due to the fact that the aquaponic system could only be monitored while the building was occupied, any floods during the night could be significant in size. Switching the system off at night to rectify this was not an option either because it is of critical importance that an aquaponic system is continuously operational to maintain bacterial activity and guarantee the wellbeing of the fish. Hence, the decision was made to change the design to an ebb and flow system, which would utilise syphons to manage the water height within the grow beds. The use of syphons allows the media within the grow beds to be fully submerged for a brief period - improving water contact with the bacteria colonies that process the ammonia - before the water is drained from the media bed to the fish tank below - improving both the oxygenation of the fish tank and the root zone above.

The final design for the small-scale aquaponic system consisted of a large fish tank, small aquatic pump, four covered grow beds with syphons into which expanded clay balls, and perlite would be placed, a length of garden hose, a grow lamp and light reflectors to maximise the light capture on the growing plane. The expanded clay balls also referred to as hydroton or leca, act as the primary location for biological filtration due to the porous nature of the material and high surface area. The use of perlite - which is a naturally occurring volcanic glass - acts as the anchor point that plants can utilise for stability due to its smaller particle sizes. The use of perlite also allowed the direct germination of seeds within the aquaponic system, which in a larger system would have to be done elsewhere. The size of the expanded clay balls are too large to allow this to occur because the seeds would simply fall from through the gaps and stay submerged in the water.

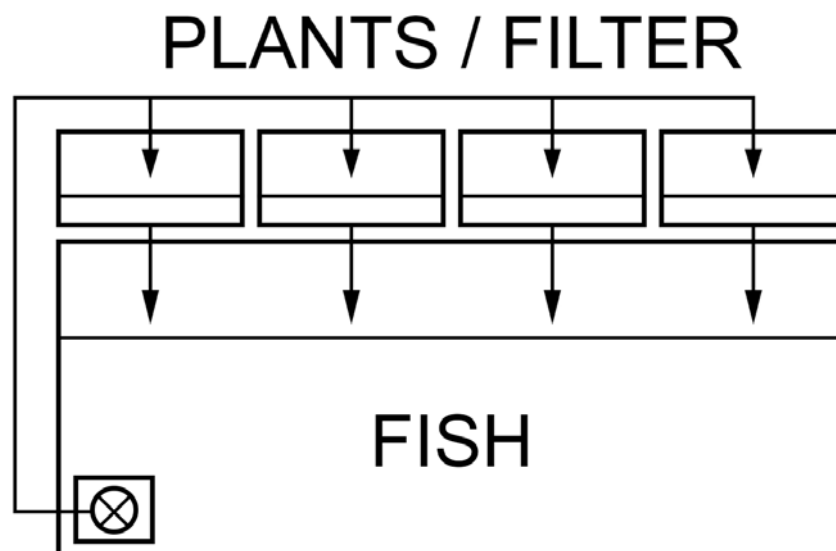


Figure 5.9 - Final design for the small-scale aquaponic system

5.2.2 - Construction

The first course of action was to source the materials and tools required to build the system. The full list of components and tools are listed below:

- 4no. grow bed
- 4no. grow bed inserts
- 4no. grow bed cover

- bag of hydroton
- bag of perlite
- hose
- 1no. hose stop-end
- 1no. grow lamp
- string
- 1no. water pump
- 1no. jubilee hose clip
- plastic mains water pipe
- 4no. A3 card
- low-density foam

Tools required:

- scalpel
- hand saw
- screwdriver

When the remaining components had been purchased it was then possible to start constructing the system. The most complex element of the design was to build the working syphons. During this period of time, a concerted effort was made to find any information on syphon construction, but very little was found. It was, therefore, a heuristic process that brought about the successful operation of the syphons. The first step was to cut a hole in the bottom of the grow bed and push the mains water pipe through the hole to create the inner portion of the syphon, which was then sealed around the base of the grow bed to ensure it was watertight. The first iteration of the syphon development saw the use of the mains water pipe with a plastic test tube cover. However, the inner distance between these two elements was too small to allow the syphon to activate (see figure 5.10). Hence, a larger outer element was required to allow water to freely flow into the syphon chamber and out of the smaller pipe to the tank below.



Figure 5.10 - Initial syphon design

During this testing phase, a multitude of different objects were used as the outer element to understand the basic principles of the syphon and to explore which combinations worked best; this ranged from the use of soup containers to coffee mugs and glass jars. Ultimately the glass jars and coffee cups gave the most reliable results and as such, formed part of the final prototype (see figure 5.11). Once the syphons were operating as expected, it was then time to fill the fish tank and place the four grow beds - with working syphons - on top of the fish tank. Conditioning solutions can be added to the water to ensure that the chlorine content is lowered to tolerable levels in preparation for the introduction of fish. However, this occurs naturally if the water is left for a few hours before fish are placed in the tank. A small aquatic pump was placed into the tank, and a length of hose stretched along the back of the grow beds, into which a number of holes were punched, to distribute the water evenly. The grow bed covers needed to be notched out to ensure the hose could stretch along the back of each grow bed unimpeded. When the small-scale system was first switched on it became immediately apparent that the pump was undersized to maintain sufficient water pressure across all the holes in the hose pipe. Therefore, some holes were covered with electrical tape to ensure all grow beds received a fair share of the water supply. During testing, the water moved

around the system as planned; from the pump to the four grow beds, through the activated syphon and back to the tank. Upon successfully testing the system, the small-scale aquaponic system was completed by filling the grow beds with hydroton (see figure 5.11) - which would form the biological filtration - onto which a grow tray would be placed which was filled with perlite to ensure proper root support (see figure 5.12). Finally, a thin strip of foam was added to each grow bed where the water entered, to capture any solid waste from the fish.



Figure 5.11 - Grow bed with lower layer of hydroton, glass jar syphon, foam filter and hose



Figure 5.12 - Grow bed with upper grow tray filled with perlite

To be able to add the fish safely the system it first needed to be ‘cycled’. The process of cycling is the gradual addition of ammonia to the system to help build up the bacterial populations in the hydroton and perlite. This allows a sufficient population of bacteria to be ready and waiting when the fish are finally added (Bernstein, 2011). The system was completed towards the end of December, in a building that was not heated, so the fish species that was selected for the system would have to be able to survive in very cold conditions. This led to the decision to use carp as they are both indigenous to the UK and very hardy, which not only made them the perfect choice for the system during the winter season but also meant they would be able to handle any swings in water chemistry if for any reason the system did not perform as expected. In total five small carp were added to the system, which were donated by a local aquaculturist who was interested in the project. Although the stocking of the system was half that started by Bernstein (2011), it was a purposeful decision to ensure the wellbeing of the fish while the system matured and knowledge was acquired. Once the fish had been added to the system it was then left to run for a week to ensure it could support the fish without any external involvement. Finally, a grow light was suspended from the ceiling, and card

reflectors were made to ensure the maximum amount of light was hitting the growing surface, which would hopefully maximise crop growth.



Figure 5.13 - Completed small-scale aquaponic system

As the first week passed, the fish were still happy and healthy, so seeds were added to the system, which included basil, coriander, rocket lettuce, parsley, mustard greens and garlic chives. The seeds of these three crops were pushed into the perlite and left to germinate in the damp environment. After a week, the seeds began to germinate, and the first signs of life were observed (see figure 5.14). Two weeks later, the seed leaves had appeared, and the crops were starting to form (see figure 5.15).



Figure 5.14 - Small-scale aquaponic germination



Figure 5.15 - Small-scale aquaponic system after two weeks

After approximately eight weeks the small-scale aquaponic system had produced a full crop of coriander, rocket lettuce, parsley, mustard greens and garlic chives. The basil never progressed past its seed leaves, which was surprising because basil is a widely grown plant in aquaponic and hydroponic systems. However, this may have been due to the drastically reduced temperatures within the building.



Figure 5.16 - Small-scale aquaponic system after eight weeks

5.2.3 - Inputs and outputs

This initial small-scale aquaponic system was a proof of concept and provided an opportunity to collect knowledge on aquaponic systems that would otherwise be difficult to obtain through desktop research. Therefore, the time spent on the system was focused on the constraints and opportunities of aquaponic systems, which could help in the development of the larger system. The fish were fed a simple pinch of food every other day due to the low temperatures, and there was a harvest at the end of the experiment. The fish were never harvested as they became mascots for the Biospheric Project and would later be donated to a local school. The system cost approximately £100 excluding the fish tank, which was donated, and performed better than expected during the colder winter months.

5.2.4 - Knowledge acquired

Before the small-scale aquaponic system was developed, very little was known about aquaponic systems. However, through the process of designing, constructing and commissioning the small-scale aquaponic system a basic level of understanding was achieved relating to fish husbandry, crop germination, crop husbandry, biological filtration, solid filtration, pumps, plumbing and the maintenance of all these elements. Although the knowledge acquired was heuristic - i.e. consisting of rules of thumb and best practices - it would be invaluable in the delivery of the larger scale aquaponic system, which would start to be constructed only a few months after the first harvest from the small-scale aquaponic system.

5.2.5 - Future adaptations and considerations

If the system was to be built again, there are two key elements that would be designed in a slightly different manner. The first is that by combining plant growth and filtration in the same element, it made it difficult to maintain one function without affecting the other. Algae growth was prominent throughout the grow beds, which kills the beneficial bacteria by restricting their access to nutrients and oxygen. This reduces the efficacy of the biological filter, which in turn affects fish health and reduces crop growth. In this particular system, it was not possible to remove the media for cleaning as it was also the substrate for growth. It would, therefore, be beneficial in future systems to separate biological filtration, solid filtration and crop growth into separate elements, which would allow all items to be maintained individually. The second amendment to the completed design would be to have a more powerful or even oversized pump that could be throttled back through the use of an escape valve back into the tank. This would allow some scope to change the flow rates if required or expand the system at a later date. The pump purchased for this system was running at its maximum flow rate, and in some cases, the syphons did not engage because the flow rate was too low.

5.3 - Large-scale experimentation

From the moment the seeds were sown in the smaller system attention turned quickly to the design and development of the larger system. The development of the larger system would be far more challenging due to its increased size, increased weight and increased productivity. Before work started, it was known that the weight of the aquaponic system, which was dependent on large bodies of water to maintain fish health, was going to be the primary constraint facing the integration of the system. Having spent countless weeks searching for similar systems across the world as a starting point, it seemed that all large building integrated aquaponic food systems were constructed at ground-level due to the obvious limitations posed by constructing an aquaponic system above ground-level. In a similar way to the Gary Comer Youth Centre mentioned in the previous chapter, new buildings could be designed from the outset to support the weight of heavy fish tanks and to support the other elements associated with an aquaponic system. However, in most cases, existing buildings are not designed in this way and are typically unable to support the addition of such heavy loads in a safe manner. Due to the occupation of the ground floor by two automotive garages, the large aquaponic system would have to be located either on the first floor or the second floor of Irwell House. As a result, it would be critical to understand the structural limitations of the building in order to make informed design decisions relating to the placement of primary elements. The design team, therefore, set its sights on integrating a large-scale aquaponic system above ground level - referred to as the 'elevated aquaponic system' from hereon - into a building that was not only very old but also in much need of repair.

5.3.1 - Irwell House structural assessment

In April 2012, MB Structural Engineers were appointed by MIF to assess the condition of Irwell House and calculate what the building was capable of supporting. This initial survey identified that the beam and block floor construction of the second floor could only support 3.5 kN/m^2 , which is approximately 350 kg/m^2 (see Appendix B). When talking in terms of water for an aquaponic system, this identifies a maximum water depth of 350mm, which does not take into account the weight of the fish tank, supporting structure, grow beds or people walking around it. At the very beginning of the design process, it was envisioned that the elevated aquaponic

system would be broken up into several self-contained pods that were placed up against the south facing windows of the second floor. The use of pods would allow the crops to be protected to a certain extent - much like crops grown within plant factories - while their location up against the exterior windows would provide a significant proportion of the light required for successful crop growth. However, this idea was quickly dismissed after receiving the first structural report due to the structural limitations of the floor, which in reality could only support a water depth of approximately 250 millimetres when all other elements were present; far below what would be required by the fish to maintain high levels of wellbeing. Once the structural capacity of the building was known, and the knowledge from the small-scale aquaponic system was acquired, the design ethos for the project changed radically. The following pictures illustrate the damage to the building caused by many years of neglect such as the failure of window lintels, water ingress and surface cracking.



Figure 5.17 - Surface cracking to the screed of the second floor slab



Figure 5.18 - Failed concrete lintel due to water ingress



Figure 5.19 - Water damage to roof structure

5.3.2 - Elevated aquaponic system - Early designs

Once it was known that the placement of aquaponic pods up against the exterior south-facing windows was no longer an option, the dilemma of providing light to the system became apparent. One of the key arguments for designing an aquaponic system in comparison to say a plant factory, for example, is that it could be naturally lit; minimising its dependence on the electrical grid for crop growth. By pushing the growth of crops deeper into the building - where the structure was stronger - it became evident that the system would have to depend on the use of artificial lighting due to severely diminished levels of natural light; destroying one of the fundamental aims of the project. To rectify this, a bold design decision was made to locate the heavy aquaculture components of the aquaponic system where the building was strongest and darkest - i.e. in the middle of the second floor - and to relocate components responsible for crop growth to where natural light was abundant - i.e. onto the roof. This radical departure from the original design ethos of self-contained aquaponic pods on a single floor to a design that bridged the top floor and roof of the building added an unanticipated level of complexity to the project. However, this design decision would ultimately allow more crops to be grown - due to the expansive area of the roof when compared to a few windows - without the need for artificial lighting.

With the structural limitations of the building now known along with a new conceptual arrangement for the large-scale aquaponic system, it was important to revise the initial design. This would be achieved by first reducing the volume of the fish tanks while increasing their number to provide an increased fish population to support a larger growing area, which would also provide greater flexibility when locating fish tanks within the building. In order to combat the structural limitations of the floor, it was decided that the heavier elements of the system - i.e. the fish tanks and filtration unit - would be best placed directly above the primary steel beams of the building, which were expected to be able to carry much more weight than. By creating a number of smaller tanks, it was envisioned that the resilience of the system could also be increased as a byproduct of the redesign. This is because a number of different species could be kept within the same system, and if any tank showed signs of infection or disease, it could be quarantined without affecting the rest of the fish population. The addition of crop growth to the roof, although allowing for a more

productive system, would also create numerous additional complications, such as the need for edge protection and public access to the roof itself.

In figure 5.20, the initial design for the revised arrangement of the aquaponic system can be seen. This design positions twelve fish tanks in the middle of the second floor, where access to light is poor, with three fish tanks along each of the four sides. The four columns that square off this arrangement have primary steel beams spanning between them, which ultimately provide the required support for each fish tank; weighing approximately 850 kilograms each. This initial design also included the provision of a vermiculture systems and mushroom production on the second floor.

The design for the roof space can also be seen, which shows a large aquaponic polytunnel - marked in green - that contains a succession of media beds along with a long water culture system. The secondary polytunnel - marked in blue - was identified as a place in which to house a hydroponic system - if both roof structure and budget allowed. The roof design also included the provision of few raised beds - marked in red - which would highlight a third method of urban rooftop food production. The design for the roof followed the same structural principles as the second floor; i.e. to locate aquaponic elements on top of structural beams to minimise the structural stress applied to the roof structure. As mentioned previously, this initial design contradicts some of the points made in the previous chapter because the design was conceived well before the knowledge of integrated food systems was acquired as a result of the design and development process. Hence, the placement of a water culture system and raised beds on the roof would not be a safe strategy, in reality, especially considering the condition the of the building.

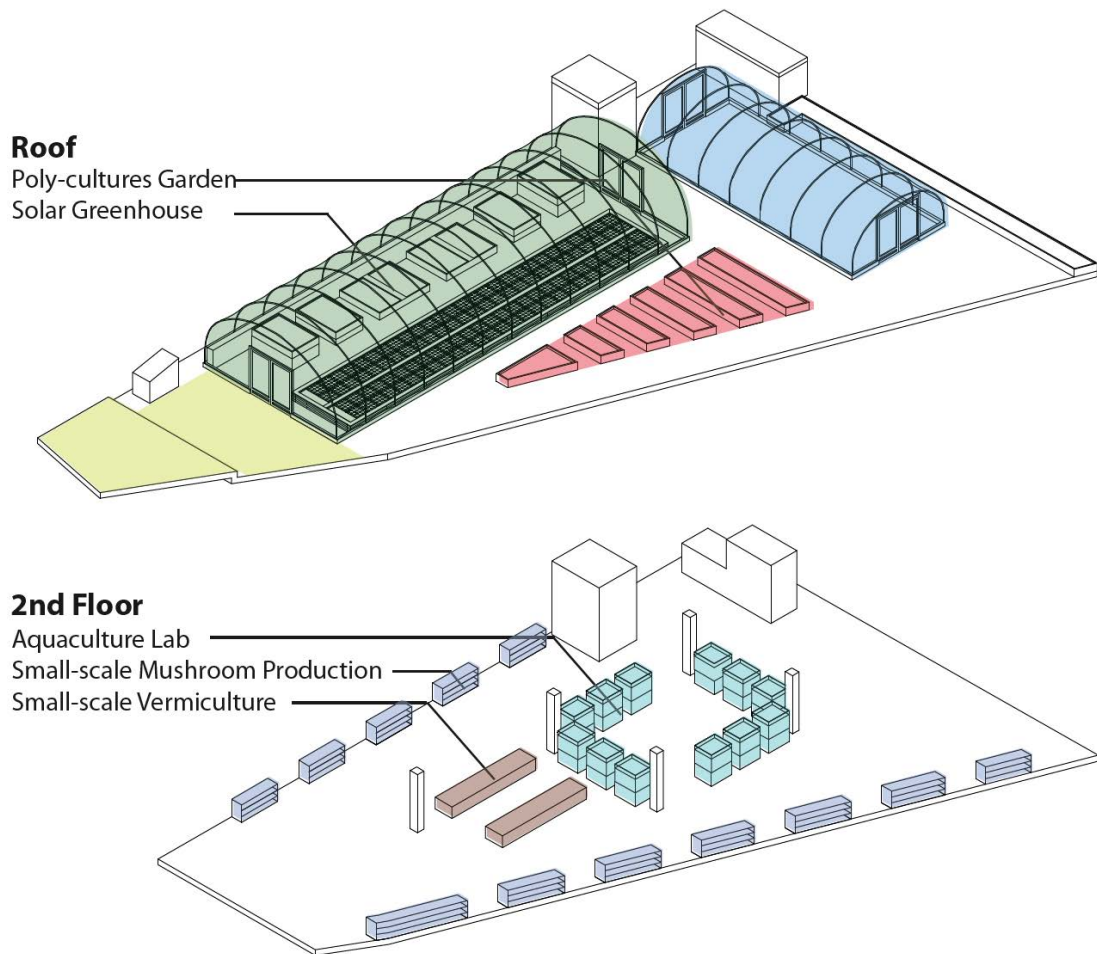


Figure 5.20 - Initial large-scale aquaponic system design

From the outset of the biospheric project, it was intended that an aquaculture or aquaponic consultant would be required to provide much-needed support relating to fish tank densities and fish husbandry, for example. Aquaponics UK, who are specialist in the design and operation of aquaponic systems, were contacted early on to contribute to the project. However, due to budget constraints, any additional consultants to structural engineers would have to provide services ‘in kind’, which Aquaponics UK were not willing to agree to for obvious reasons. However, as a gesture of good will, Aquaponics UK were willing to offer remote support with regards to the relationship between the growing area, fish tank volumes and overall fish weight, which were pressing queries that needed resolving. Through conversations with Rebecca Bainbridge at Aquaponics UK (see Appendix C) it was discussed that such a large-scale aquaponic system would require at least three fish tanks to support three different stocking densities as the fish matured; i.e. 20kg/m^3

for fish weighing between 20g - 100g; 25kg/m³ for fish weighing between 100g - 260g; 30 kg/m³ for fish weighing between 260g-450g. Again, based on conversations with Rebecca Bainbridge, it was calculated that 166.66 kilograms of fish would be required to supply the nutrient requirements of a 100m² growing on the roof. This was based on 50 grams of fish food for every 1m² of growing area and at a feeding ratio of 3 percent of total weight of fish. Taking the weight of fish required to support 100m² as a base point, it could then be calculated how many fish each of the three fish tanks required to meet the nutritional demands of the crops; which was estimated to be 365 fish in the 20g - 100g tank, 354 fish in the 100g - 260g tank and 347 fish in the 260g - 450g tank. This would equate to a low-density tank with a volume of 1.825m³ in size, a medium-density tank with a volume of 3.682m³ and a high-density tank with a volume of 5.205m³. To provide some 'headroom' in the system, each tank volume was rounded up the next whole number. This would allow any concentrations of chemicals that were harmful to the fish to have ample opportunity to be removed from the system through biological filtration, solids filtration or crop absorption. Hence, an aquaponic system supporting 100m² of growing area would require a low-density tank at 2m³, a medium density tank at 4m³ and a high-density tank at 6m³. To suit the arrangement of fish tanks seen above in figure 5.20 - i.e. twelve fish tanks in four rows of three - the proposed tank volumes could be split very easily into 1m³ tanks; giving an arrangement of 2no. 1m³ fish tanks for the small-sized fish, 4no. 1m³ fish tanks for the medium-sized fish and 6no. 1m³ fish tanks for the larger-sized fish. With regards to improving the resilience of the system these twelve tanks could then be split into two banks for two different species; with each species receiving one fish tank the small fish, two fish tanks for the medium fish and three fish tanks for the large fish.

These guidelines, however, were calculated on the basis that the growing area on the roof would be 100m². However, the initial design only gave a growing area of 70m²; with media grow beds providing a gross area of 30m², and the water culture system providing a gross area of 40m². In order to address this issue simply without recalculation, the volume of each individual fish tank would be reduced from 1m³ to 0.7m³ to address the required reduction in fish population whilst maintaining stocking densities. Hence, a 1m x 1m x 0.7m tank could be used to achieve the required fish numbers and densities for a reduced growing area. Once the initial design was complete, and the fish tanks were sized correctly for the system, the design was

marked out at a 1:1 scale in chalk on the second floor to give a better idea of the size of the system to the design team, structural engineer and the festival. This was a beneficial process to undergo as it allowed the entirety of the system to be viewed in one place before a single length of timber or water pipe was cut. The designs for the roof were also marked on the second floor in a dashed line to ensure they were not washed away by the rain and to start the process of understanding how the different elements would be connected to form a recirculating system.



Figure 5.21 - Chalk outlines of large-scale aquaponic fish tanks



Figure 5.22 - Chalk outlines for the proposed roof design

5.3.3 - Structural implications of the revised design

With the amended aquaponic design now utilising the roof, it was required, much like that of the second floor, to assess and understand its structural condition and capacity. The revised designs were submitted to the structural engineer to ensure that the roof could support the proposed loads of the system and the structural beams could support the central block of twelve fish tanks at second-floor level. The amended placement of the fish tanks was acceptable; however, it came with a proviso that the number of people in each structural bay had to be restricted to 15 people to stay within the structural limitations of the steel structure. With regards to the design for the roof, it had initially been suggested by the structural engineer that each element could be safely supported by the roof construction based on the assumption that the construction of the roof was the same as the construction of the second floor (See Appendix D). However, the failing lintels above many of the windows on the second-floor would need to be replaced for any work to take place on the roof. The traditional method of replacement would be to prop the roof, remove the window, replace the lintel and then replace the window. This approach, however, would be costly and time-consuming, so an alternative option was proposed. This

alternative approach would utilise a steel beam that would span between the internal brick piers that flanked the windows; thereby bypassing the failed lintel entirely and passing the forces from the roof directly into the brickwork (see figure 5.23). A byproduct of this approach was that all the work could be conducted within the safety of the building without the need for external scaffolding; greatly reducing expenditure. It was agreed with MIF and the structural engineer that this was the most cost-effective method of ensuring the structural integrity of the roof and the progression of the project (see Appendix E).

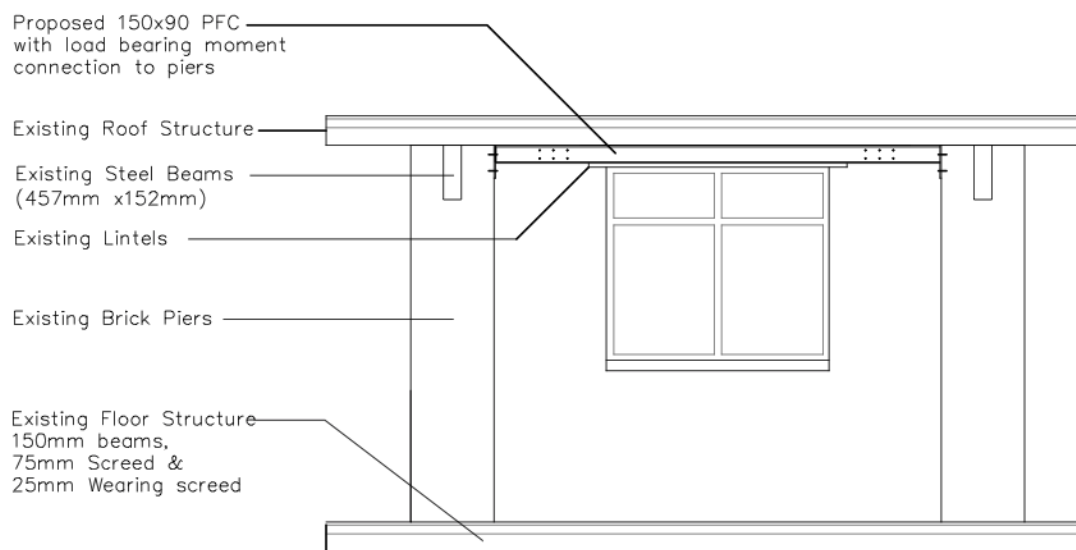


Figure 5.23 - Concept design for the internal steel lintels

5.3.4 - Amended rooftop and second floor design

In January 2013 a detailed structural survey of the roof was conducted to assess whether the roof could indeed support the proposed design. The structural report concluded that there was spare structural capacity in the secondary beams, which spanned between the primary beams, but there was no additional structural capacity within the larger primary beams to carry any additional weight (see Appendix F). Therefore, it was not possible to locate any of the elements of the design on the roof. It was essential that the crops within the system were provided with sufficient access to the natural light, but without sufficient structural capacity either adjacent to the second-floor windows or on the rooftop, the goal of eradicating the need for artificial lighting seemed to be diminishing in feasibility.

In order to rectify this issue, a radical approach would, again, be needed to ensure that the elevated aquaponic system was both safe and productive. This would manifest in the addition of a transfer floor on the roof, which would sit directly upon the steel columns below and span between them; therefore bypassing the structural limitations of the roof, and creating a firm pad on which to place the systems and polytunnel. However, there were two primary locations where this transfer floor could exist. These two locations can be seen in figure 5.24, which shows one position of the rooftop polytunnel in the same place as the fish tanks beneath - spanning between four steel columns - and another position which sits upon the northern external wall of Irwell House, spanning across to the row of three columns beneath. To maximise the growing area, it was discussed that steel angles could be utilised which would allow the floor to cantilever beyond its footprint. The options these different approaches created can be seen below, with the inner red line representing the smaller transfer floor and the outer red line representing the transfer floor with a one-metre cantilever. These options were drawn isometrically to better represent the four options, which are documented in the following pages.

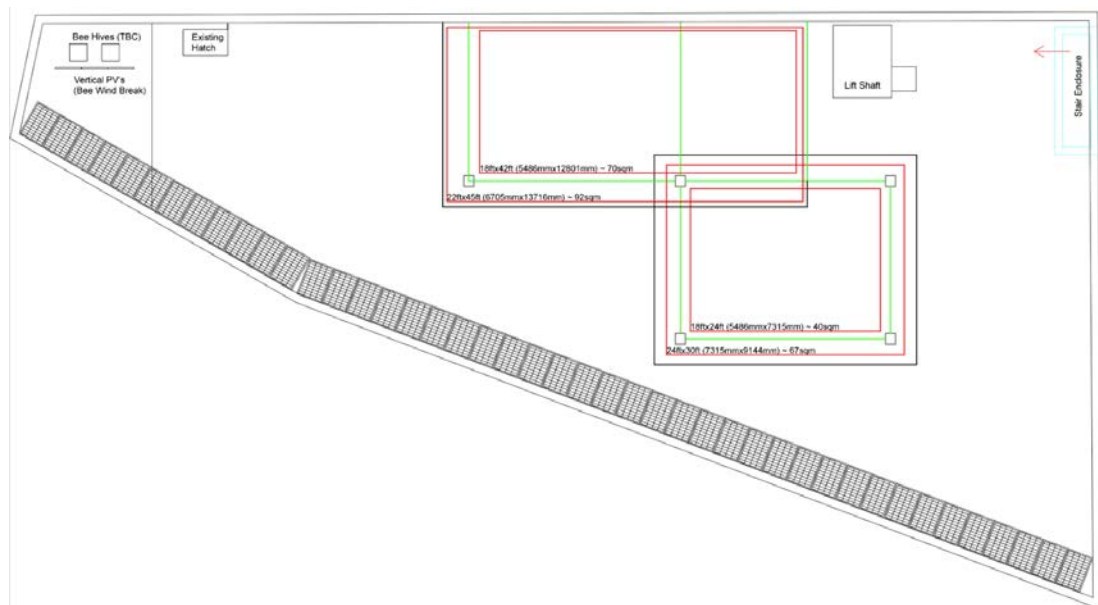


Figure 5.24 - Four options for the possible location of the polytunnel on the roof

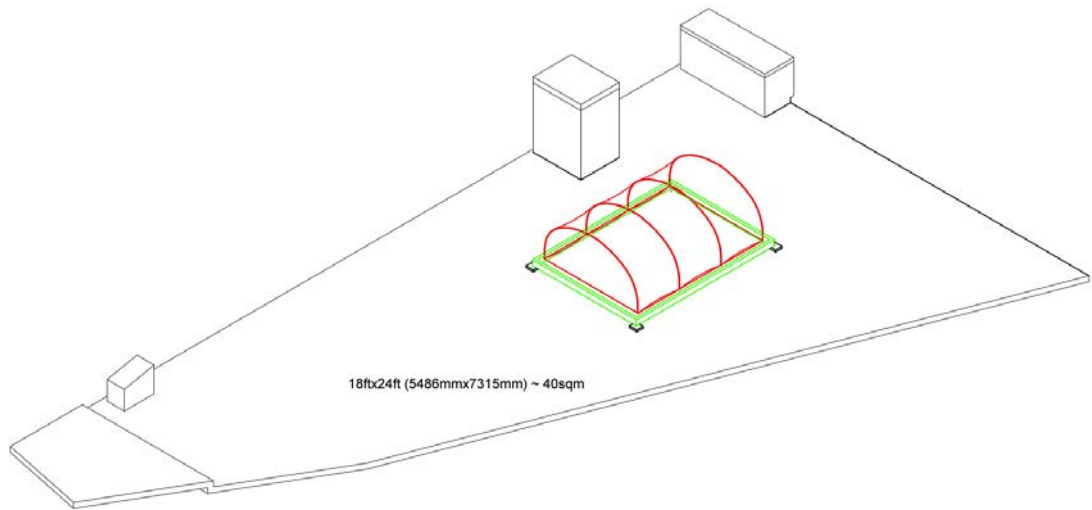


Figure 5.25 - Transfer floor option one (shown in green)

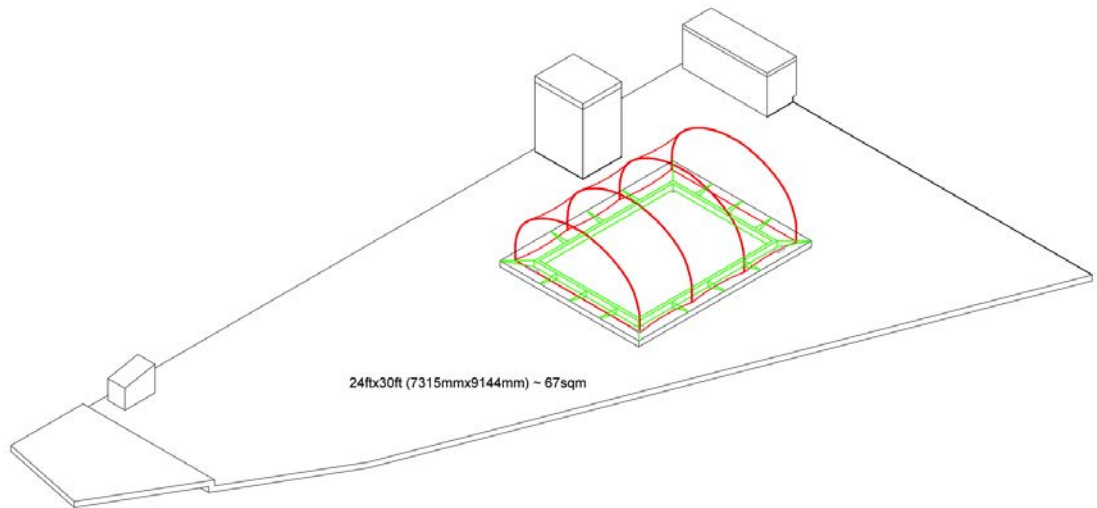


Figure 5.26 - Transfer floor option one with one metre cantilever (shown in green)

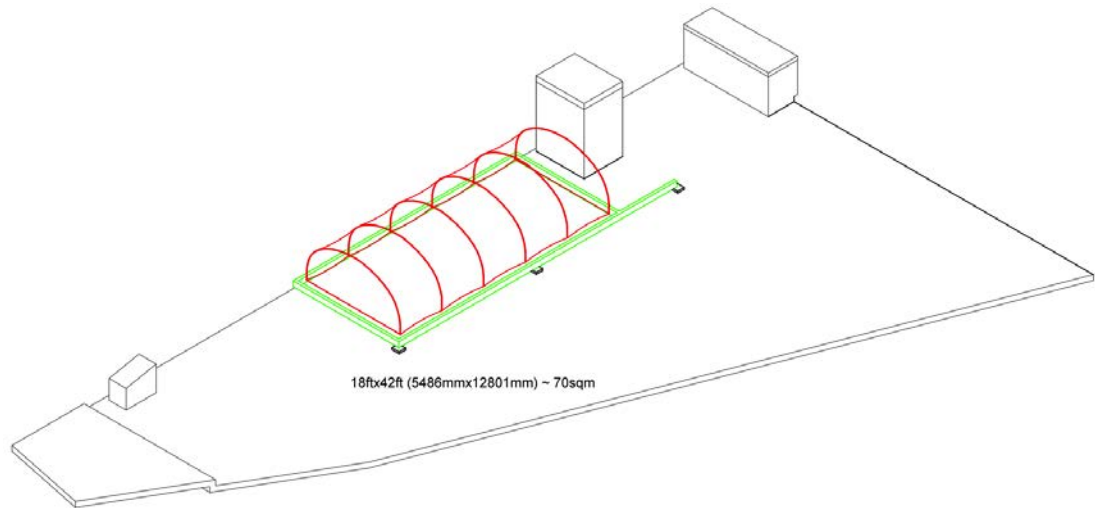


Figure 5.27 - Transfer floor option two (shown in green)

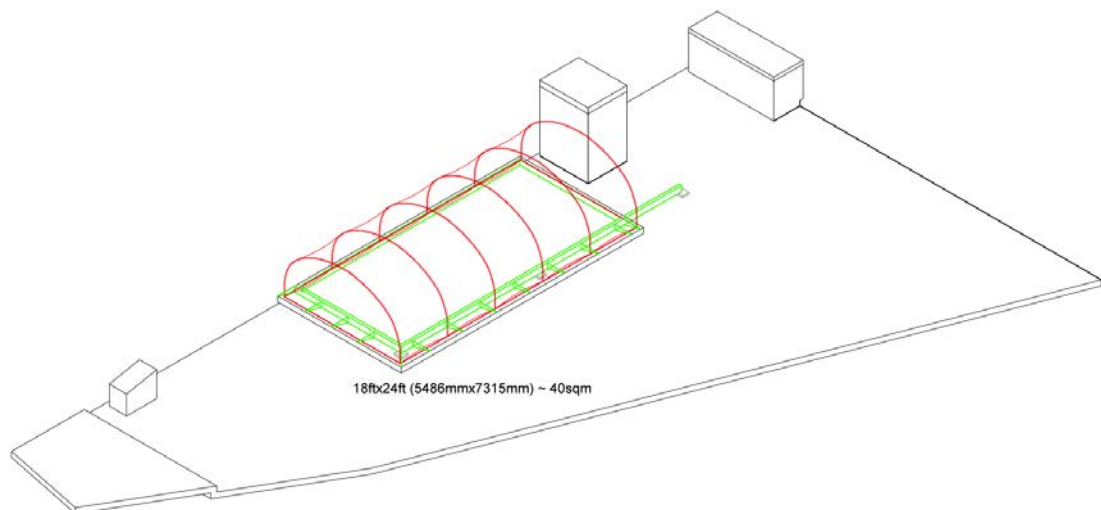


Figure 5.28 - Transfer floor option two with one metre cantilever (shown in green)

As a sponsor of MIF the Building Design Partnership, also known as BDP - an architectural and engineering practice in Manchester with offices in Ireland, China, The Netherlands, United Arab Emirates and India - were brought in to further aid the progression of the design with regards to the structural limitations of the building. Through initial discussions with BDP, it was made clear that due to the condition of the building it would be very difficult to prove the structural integrity of the exterior walls. Hence, the second option for the transfer floor would have to be rejected due to fears of structural failure. This left option one as the only feasible solution of growing crops on the roof. However, with a maximum area of sixty-seven metres squared - inclusive of the area required for circulation - when aided by a one-metre cantilever, it was much smaller than the ambitions of the project. Yet again, the structure of the building was defining the design of the aquaponic system and informing the direction of the project. At this point, and in agreement with the findings of the previous chapter, it was decided that the use of a water culture system and media grow beds on the roof should be omitted from the design, as their combined weight was restricting the progression of the project. Instead, a lightweight NFT system would be proposed, which it was thought would be able to be natively supported by the roof without any structural alterations, removing the need for a transfer floor.

The decision to utilise an NFT system on the roof, although much lighter, would still require the presence of a polytunnel to maximise the productivity of the system and to protect it throughout its lifespan. Due to the removal of the heavy water culture system, media beds, and transfer floor, the placement of the polytunnel was less constrained by the structural grid beneath. However, the weight of the polytunnel and the wind loads it would impose on the building would still need to bypass the roof construction and pass directly into the steel structure. The working principle to achieve this would be to sit the polytunnel on two transfer beams that would span the length of the polytunnel and be fixed directly to the steelwork beneath; shown in figure 5.29.

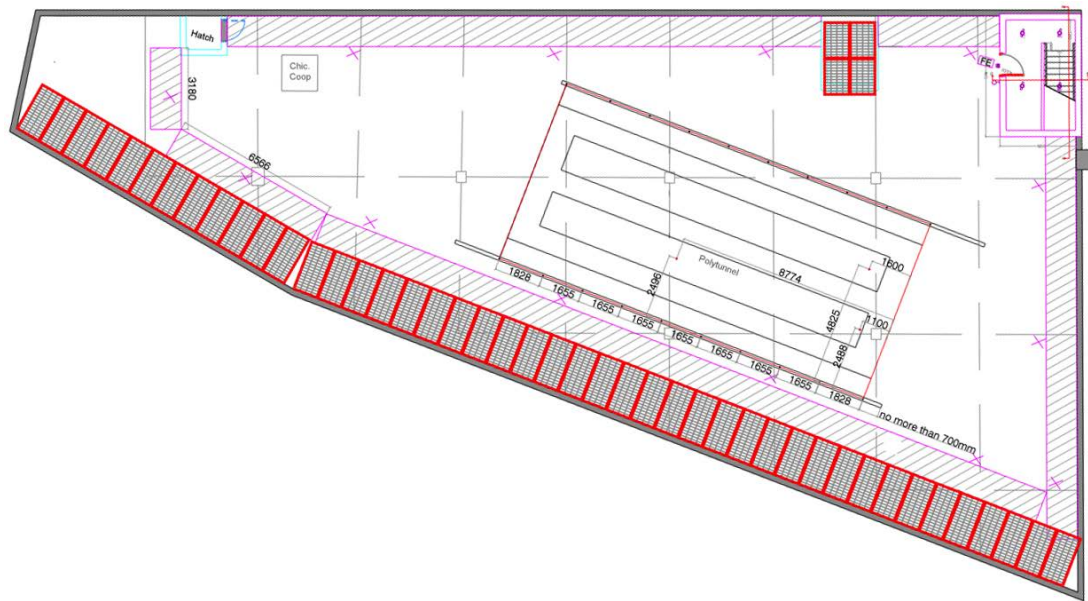


Figure 5.29 - Roof design with amended polytunnel location and possible placement of photovoltaic panels to southern edge of roof (See Appendix H for full size image)

The loss of the media beds from the roof would present the design team with an additional issue. Because media beds can be utilised for both filtration and crop growth, the omission of the media beds would also omit the main source of filtration from the system. In the previous chapter, it was explained that the filtration within an aquaponic system is key to the conversion of fish waste - i.e. ammonia - into available nutrients for the crops; i.e. nitrogen. The filtration provided by the media beds would, therefore, need to be replaced by a filtration unit elsewhere in the building. To address this, a filtration unit was conceptually added to the second floor adjacent to the fish tanks. It was designed to sit directly above a primary steel beam to bypass the structural limitations of the floor, which ultimately determined its form: i.e. long, thin and tall to maximise filtration. This filtration unit, however, would not hold a sufficient volume of expanded clay balls for the size of the system, so another solution was sought. This solution to this came in the form of a window system, which would not only provide the additional volume of expanded clay balls required to aid in filtration but it would also provide an additional location for crop growth; showcasing another method of naturally-lit food production within existing buildings as well as increasing productivity.

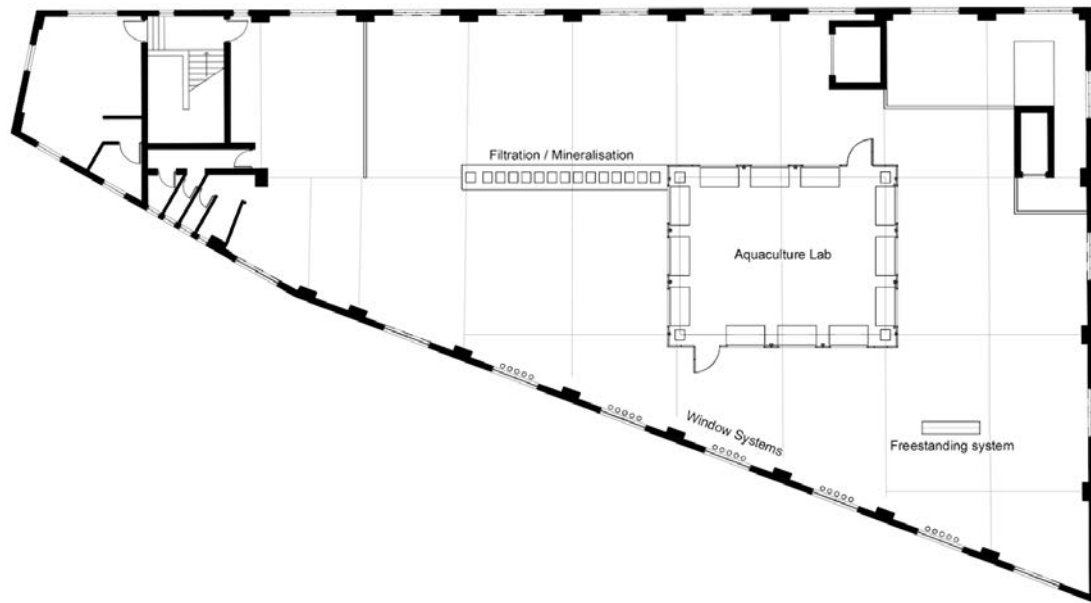


Figure 5.30 - Amended second-floor design with the addition of a filtration unit and window growing systems to south-facing windows (See Appendix H for full size image)

5.3.5 - Final structural assessment

As part of the service provided by BDP, a full structural report for the updated design was provided, which would check the structural viability of the placement of fish tanks and filtration unit on the second-floor level and the polytunnel and transfer beams on the roof (See Appendix G). The report concluded that the loads applied to the steel structure by the fish tanks and filtration unit on the second floor were ‘within acceptable loading limits’ and the change in load to individual roof beams was less than ten percent, which was outlined at the beginning the report as acceptable. The only structural alteration that was recommendation within the report, aside from the steel lintels that had already been agreed, was the need for the cleats that connected the beams to the columns to be stiffened. In preparation for the delivery of the final structural report, a single beam to column connection was broken out to identify the way in which these two structural elements were connected. Ultimately, this connection would determine how much each beam could carry, so it was imperative to calculate its strength.



Figure 5.31 - Exposed beam to column connection below the second floor slab

Unfortunately, the cleats were not a standard fixing and, as such, could not be proven to be robust enough to support the weight of the fish tanks along each beam. The structural engineers were concerned that the cleat - which connected the beam to the column - could fail along the crease. Hence, it was suggested that the cleats should be stiffened with 10 millimetres plates - welded between the two flanges - thereby reducing the risk of failure (see figure 5.32). At this stage, the design of the elevated aquaponic system was considered structurally sound and finalised in principle. This, however, was only the end of the beginning as work now needed to start on the schematic design of the system, which would later inform the detailed design of the individual components as well as the design of the monitoring systems.

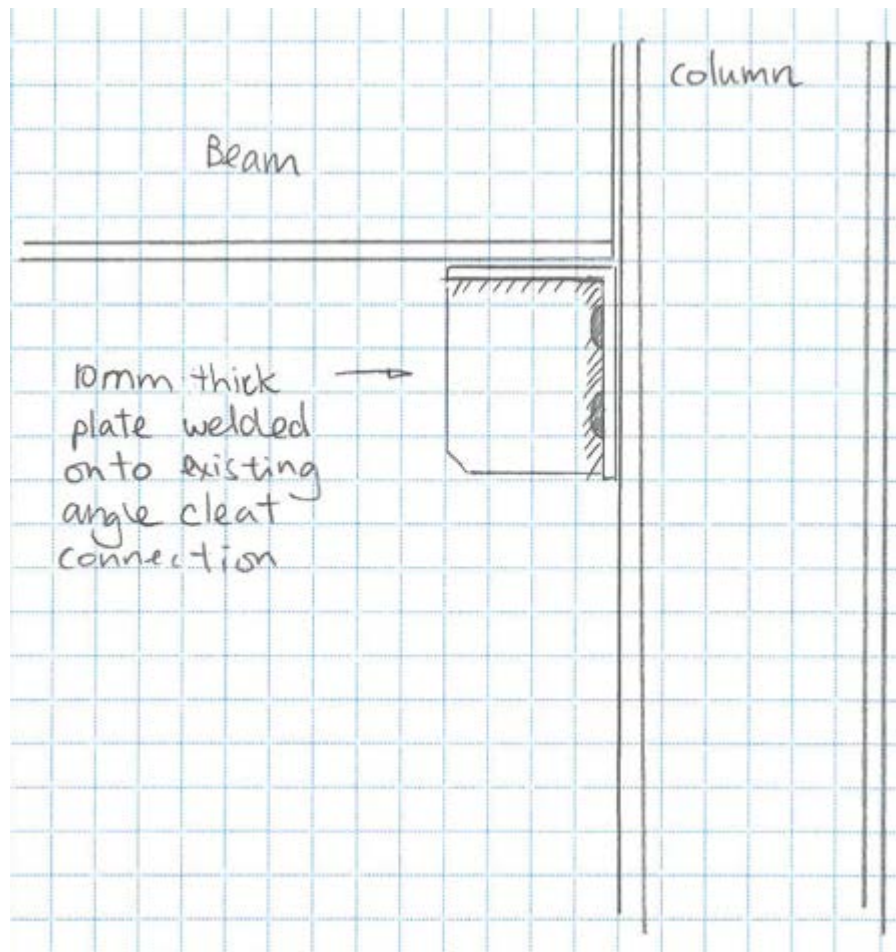


Figure 5.32 - Proposed beam to column stiffening detail

5.3.6 - Schematic design

The development of the project was dependent on not only the structural condition and capacity of the existing building but also on the strong interrelations between the different elements of the elevated aquaponic system. This started very simply by first identifying how the four key elements of the system - i.e. fish, filtration, window system and roof growing - were connected (see figure 5.33).

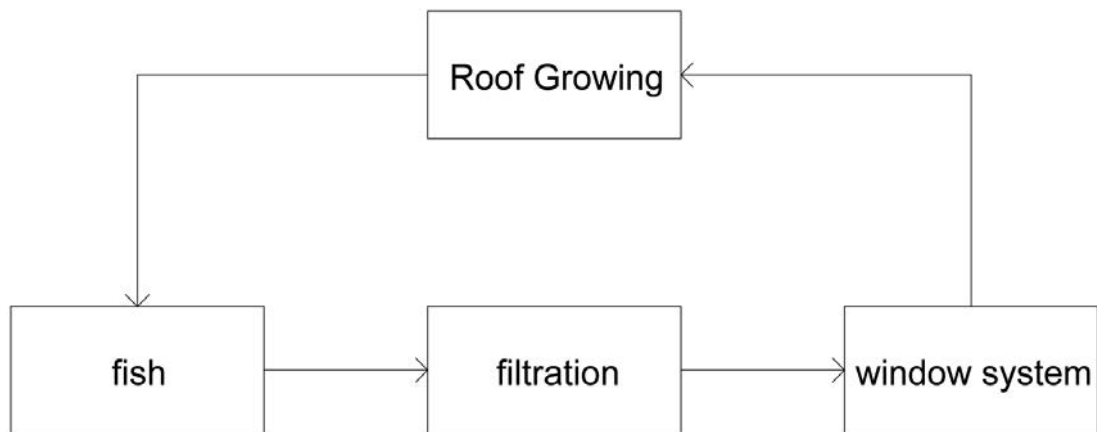
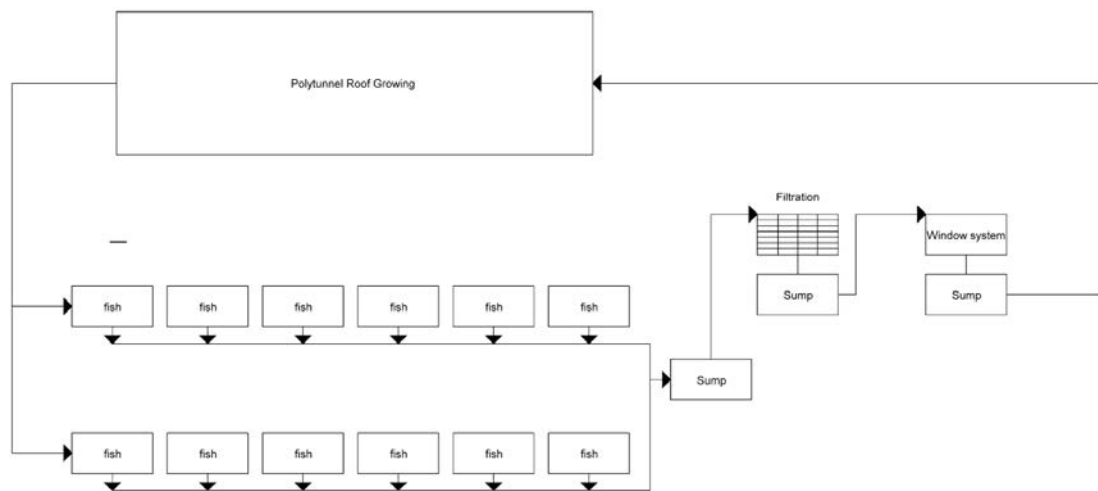


Figure 5.33 - Simplified schematic design for the elevated aquaponic system

This simplified schematic would form the foundations for the development of the schematic design as it progressed. As mentioned previously, the twelve fish tanks could be split into two banks of six, thereby providing the opportunity to stock two different species of fish. This was initially conceived as a way to keep the two fish systems separated by draining each bank of tanks into its own sump. However, once the water was pumped into the next stage of the system - i.e. the filtration unit - the two bodies of water would mix rendering the need for two sumps redundant. Not only this, but it was noted that balancing the system - i.e. avoiding the situation where one sump was overflowing while another one was running dry - would be a difficult challenge to overcome. By removing one sump from operational duties, this would eliminate a pump from the system - taking the number of pumps down to three - and reduce the complexity of the design. The elevated aquaponic system would still comprise of two species of fish to improve resiliency, but it would just be the case that each tank could be quarantined if needed, rather than keeping the water from one fish species away from the other, and vice versa. These decisions culminated in an updated schematic which included individual fish tanks and sumps. This schematic can be seen in figure 5.34, whereby the water from the fish tanks drains into a single sump, where it is then pumped to the top of the filtration unit, left to fall through the media, then pumped to the top of the windows system, where it is allowed to drain through, and then pumped to the NFT systems on the roof, where gravity takes over; supplying the crops with water and nutrients and returning to the fish tanks on the floor below. This schematic shows the basic linkages between the

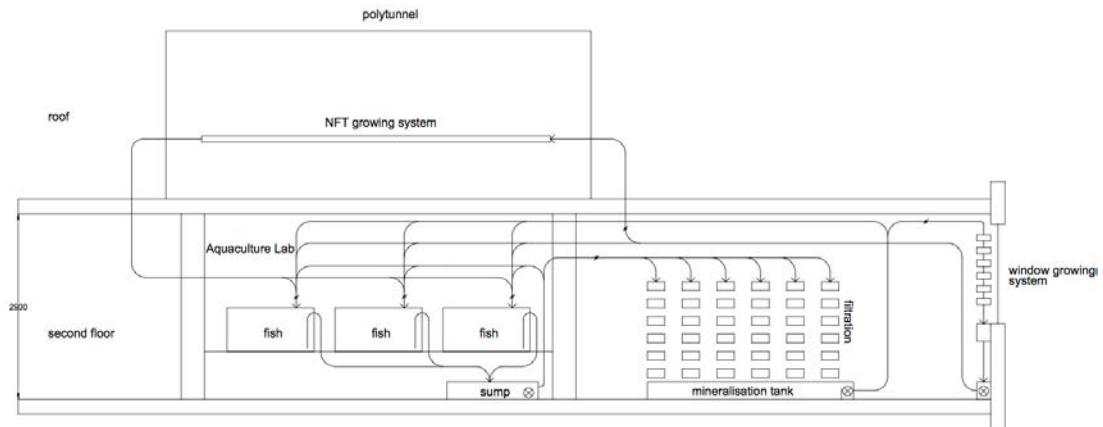
fish, filtration unit, window system and NFT system. It does not, however, include any feedback loops, which would be required to balance the system.



*Figure 5.34 - Intermediate schematic design for the elevated aquaponic system
(See Appendix H for full size image)*

The notion of ‘balancing’ the system is the act of ensuring that the volume of water leaving one sump per unit of time is the same as the volume entering it per unit of time; i.e. that all the pumps within a given system are moving the exact same volume of water at any one time. Simply purchasing three identical pumps is not a solution to this because each pump is fighting against different forces, such as the number of turns in the water pipe, the number of outlets, decreasing sizes of pipework and the height the water needs to be moved. The pumps, therefore, needed to be balanced manually to negotiate the different aspects that affect the movement of water from each pump. The balancing of the system was initially achieved through the use of a valve and a ‘backflow’, that simply offered an opportunity for the water to flow back along the system, dependent on the position, or intermediate position, of the valve. For example, if one of the three pumps within the elevated aquaponic system was only able to move seventy-five percent of its maximum flow rate onto the next component of the elevated aquaponic system, then the other two pumps would have to match this to avoid flooding. This was conceived as a succession of pipes that sent water back to the fish tanks; i.e. to the ‘beginning’ of the system. Ultimately the twelve fish tanks have a larger capacity that could be used to help balance the system or at least give enough time for the problem to be

identified and rectified without flooding the building. This additional level of complexity helped finalise the schematic design of the system, which can be seen below in figure 5.35.



*Figure 5.35 - Final schematic design for the elevated aquaponic system
(See Appendix H for full size image)*

5.3.7 - Fish and crop selection

Much like any aquaponic system, the elevated aquaponic system is dependent on the symbiosis between fish, naturally occurring bacteria, and crops. However, for this symbiotic relationship to occur in any shape or form, the system needs to be stocked with fish and crops. The fish species that were utilised within the system were red Nile tilapia and common carp. This decision was based on a compromise between hardiness, native species and rate of growth. Tilapia are one of the most commonly used fish species within aquaponic systems due to their resilience to rapidly changing environments as well as their speed of growth. Carp, on the other hand, are slower growing but are a UK native species and are also very resilient. The goal of the system was to design a one hundred percent native system so as to eradicate any biosecurity issues, but due to a relatively simplified knowledge of fish husbandry, the decision was taken to use tilapia over any other UK species, such as trout or perch, as this would reduce the likelihood of poor fish health as a result of the design team's actions. The long-term goal of the system was that when the tilapia were gradually harvested from the system, they would be replaced with UK native species, in time for the winter period. Both the carp and tilapia that were stocked in

the system were bought as table fish - i.e. suitable for human consumption - and the tilapia were secured from an organic producer. Both of the fish species would be fed their own organic fish feed to improve the organic credentials of the system, even though the carp were not certified organic.



Figure 5.36 - Red Nile tilapia in the elevated aquaponic system

The crops for the system were determined based, again, on a compromise between crops that are known to grow well within aquaponic systems and crops that are less well known but offer an opportunity for better economic return. Hence, the crop list for the rooftop NFT system included lettuce, strawberries, chard, kale, Thai basil, electric daisies, mustard greens and cabbages. The window systems, due to their deeper grow bags, could accommodate larger plants with fruiting bodies. Therefore, the crop choice for the window system included several different varieties of tomatoes, peppers, chilli peppers, courgettes and runner beans. To reduce the risk of disease outbreak and pest infestation in the polytunnel and window systems, a poly-cropping approach was taken, whereby all the crops are grown interspersed with one another rather than in banks of the same species. Increasing the diversity of crops within the system improves the overall resilience of the system, and by

designing a planting scheme that combines crops with different physical attributes and disease susceptibilities, disease and pest infestations can be contained and easily treated.



Figure 5.37 - Common carp in the elevated aquaponic system

5.3.8 - Monitoring

Monitoring equipment provides a noninvasive method of continually checking the health of the system, allowing problems to be quickly identified and remedied, or automatically adjusted depending on the severity of the issue. For example, if the temperature of a fish tank drops below a certain temperature, a tank heater can be switched on but if the flow rate along a pipe reaches zero in a multi-pump system - possibly identifying a blockage, pump failure or breach - the entirety of the system can be automatically shut down to avoid flooding. The monitoring of an aquaponic system remotely further minimises the involvement of humans in the natural ecosystem that is created, allowing it to exist without much interference apart from maintenance, planting, and harvesting. The monitoring of the elevated aquaponic system was seen both as a key part of the success of the system - both long-term and during the festival - as well as a key element of the research because it allowed

the design team to understand how humans might engage with building integrated technical food systems in the future. In a perfect world, there are a multitude of metrics that any urban farmer would like to be able to monitor at any one time. These include both aquaponic metrics such as pH level, fish tank temperature and available nutrients in the water for crop growth, as well as building metrics such as building temperature, energy use and humidity. The full list of metrics an urban aquaponic system could make use of are listed below. However, not all of these metrics are as critical as one another and the cost associated with implementing all the equipment required to deliver these metrics would cost more than the system itself.

Live building information

Temperature within the building (°C)
Relative humidity within the building (%)
Energy production - i.e. solar panels (kWh)
Energy consumption of the building (kWh)
Energy consumption of the aquaponic system (kWh)

Aquaponic basic services live information

Temperature of the fish tanks (°C)
Temperature within the polytunnel (°C)
Heat loss/gain of water returning to the tanks after it had circulated the system (°C)
Relative humidity of the polytunnel (%)
Ventilation rate of the polytunnel (L/s)
Carbon dioxide level within the polytunnel (ppm)
Light intensity within the polytunnel (lux)
Water flow rate (L/hr)

Water chemistry

Acidity/alkalinity (pH5-pH10): warnings below pH6 and above pH8
Dissolved oxygen (typically 5mg): warnings below 5mg
Nitrite (0-100mg/L): warnings above 10mg/L

Nitrate (0-200mg/L): warnings above 10mg/L on returning water

Ammonia (0-15mg/L): warnings above 5mg

Potassium (0-10g/L)

Calcium (0-5g/L)

Magnesium (0-2g/L)

Phosphorous (0-2g/L)

Sulfur (0-1g/L)

Chlorine (0-0.1g/L)

Boron (0-20mg/L)

Iron (0-0.1g/L)

Manganese (0-0.5g/L)

Zinc (0-20mg/L)

Copper (0-6mg/L)

If all the above metrics were to be included within the elevated aquaponic system, the monitoring schematic would resemble something similar to figure 5.38.

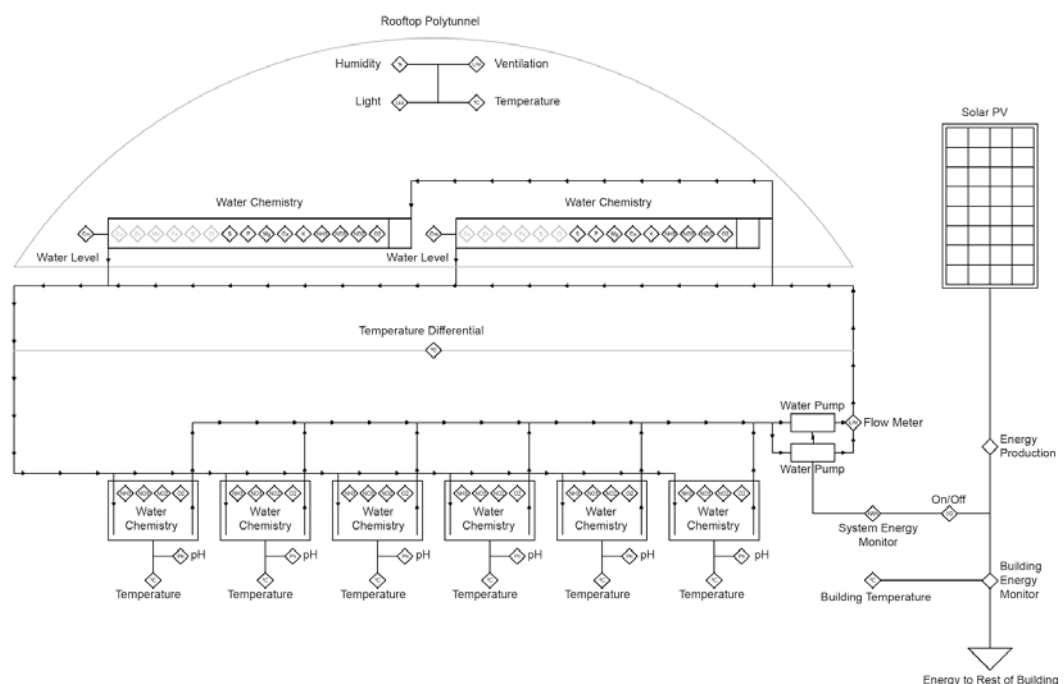


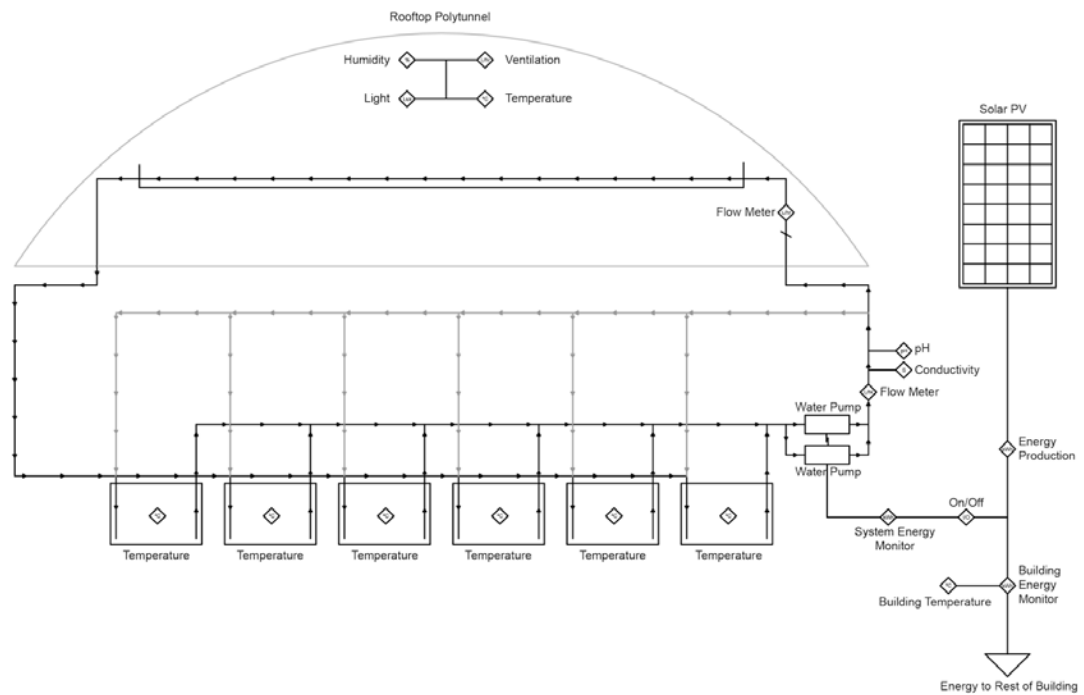
Figure 5.38 - High-complexity monitoring system

(See Appendix H for full size image)

Just as BDP had sponsored the festival and aided in the structural design of the project, Siemens was also a major sponsor and assisted in the delivery of the

monitoring equipment for the aquaponic system. As mentioned, some of the metrics listed above are more critical than others. In most cases any accumulation or depletion of nutrients in the water will manifest within the growth of the crops, allowing even a novice horticulturist to detect that something is at least not as it should be. An experienced horticulturist would most likely be able to identify the nutrients that are lacking and which are in abundance. Hence, the large number of probes that would be needed to monitor the nutrients within the system were replaced with an electrical conductivity probe. In the previous chapter, electrical conductivity was noted as a generalised method to ensure nutrients are at least available within the system, with a preferred range of 2-4 millimhos per centimetre. The pH of the system, however, is a critical value for both the health of the fish, bacteria and plants so this probe formed part of the final design for the monitoring system. The pH level can also help to identify any anaerobic bacteria that are present in the system due to the buildup of waste, which takes the available nitrate that plants require and converts it back into ammonia which is poisonous to fish. By placing a pH probe after each element relating to the flow of water, it can easily be seen, through a sudden drop in the pH, whether anaerobic bacteria are present, and whether an element in the system needs cleaning to remedy this.

Much like the nutrient availability within the system, the probes associated with the nitrogen cycle - i.e. ammonia, nitrite and nitrate - can be replaced with simple visual checks or simple and inexpensive water tests, such as those used to identify water chemistry in home aquariums. However, as long as an aquaponic system is sized correctly it should be capable of managing any small swings in chemical concentrations due to the ecological self-regulating nature of aquaponic systems: i.e. any rise in ammonia or nitrate should be easily converted into nitrogen without any issues. Due to this, expensive ammonia, nitrite and nitrate probes were removed from the design and replaced with inexpensive water test kits. The resulting monitoring schematic can be seen in figure 5.39, which represents a more economically efficient design that is more realistic when discussing effective replication in future aquaponic systems.



*Figure 5.39 - Revised low-complexity monitoring system
(See Appendix H for full size image)*

The final monitoring metrics of the system are as follows with the omitted monitoring sensors marked in light grey for clarity.

Live building information

Temperature within the building (°C)

Relative humidity within the building (%)

Energy production - i.e. solar panels (kWh)

Energy consumption of the building (kWh)

Energy consumption of the aquaponic system (kWh)

Aquaponic basic services live information

Temperature of the fish tanks (°C)

Temperature within the polytunnel (°C)

Heat loss/gain of water returning to the tanks after it had circulated the system (oC)

Relative humidity of the polytunnel (%)

Ventilation rate of the polytunnel (L/s)

Carbon dioxide level within the polytunnel (ppm)

Light intensity within the polytunnel (lux)

Water flow rate (L/hr)

Water chemistry

Electrical conductivity (1-5 mmho/cm)

Acidity/alkalinity (pH5-pH10): warnings below pH6 and above pH8

Dissolved oxygen (Typically 5mg): warnings below 5mg

Nitrite (0-100mg/L): warnings above 10mg/L

Nitrate (0-200mg/L): warnings above 10mg/L on returning water

Ammonia (0-15mg/L): warnings above 5mg

Potassium (0-10g/L)

Calcium (0-5g/L)

Magnesium (0-2g/L)

Phosphorous (0-2g/L)

Sulfur (0-1g/L)

Chlorine (0-0.1g/L)

Boron (0-20mg/L)

Iron (0-0.1g/L)

Manganese (0-0.5g/L)

Zinc (0-20mg/L)

Copper (0-6mg/L)

Suffice to say; an aquaponic system is reliant on a recirculating water supply.

Therefore, it is of critical importance to understand just how quickly water is flowing around the system. It is also essential to ensure that the water within the fish tanks is being replaced approximately once every hour to ensure the health and wellbeing of the fish. Placing a flow meter after each pump would allow incremental adjustment of the backflow valves to ensure the system was balanced. Within any building, it is of critical importance to that the water being moved by each pump is the same. If, for example, one pump was pushing water onto the next element of the system slower than it was receiving water, the sump would eventually overflow. Any form of flooding within an existing building is a serious event as could lead to structural issues due to water ingress, such as the corrosion of structural connections. To ensure that this

would never happen, and in addition to the backflow arrangement mentioned previously, an automated logic was put in place to ensure this event rarely occurred. This holistic automated control of the three pumps was referred to as the 'pump logic' and formed part of the delivery of software and hardware from Siemens that would eventually help run and monitor the elevated aquaponic system. This was a simple line of code within the monitoring system that utilised two level switches in each sump to determine whether the water level within a sump was high or low. This line of code would stop sumps from overflowing due to flow rate imbalance and stop pumps running dry, which could lead to mechanical damage and reduce the life expectancy of the pump. Although very simple in design, the pump logic could ultimately save thousands of pounds that would otherwise need to be spent to remedy issues relating to water ingress of existing buildings. In addition to such automated responses as killing the system if flow rates reduced suddenly, the control system was well rounded in managing water distribution, reducing the likelihood of sumps overflowing and detecting significant leaks. The diagrammatic relationship diagram of the pump logic can be seen in figure 5.40.

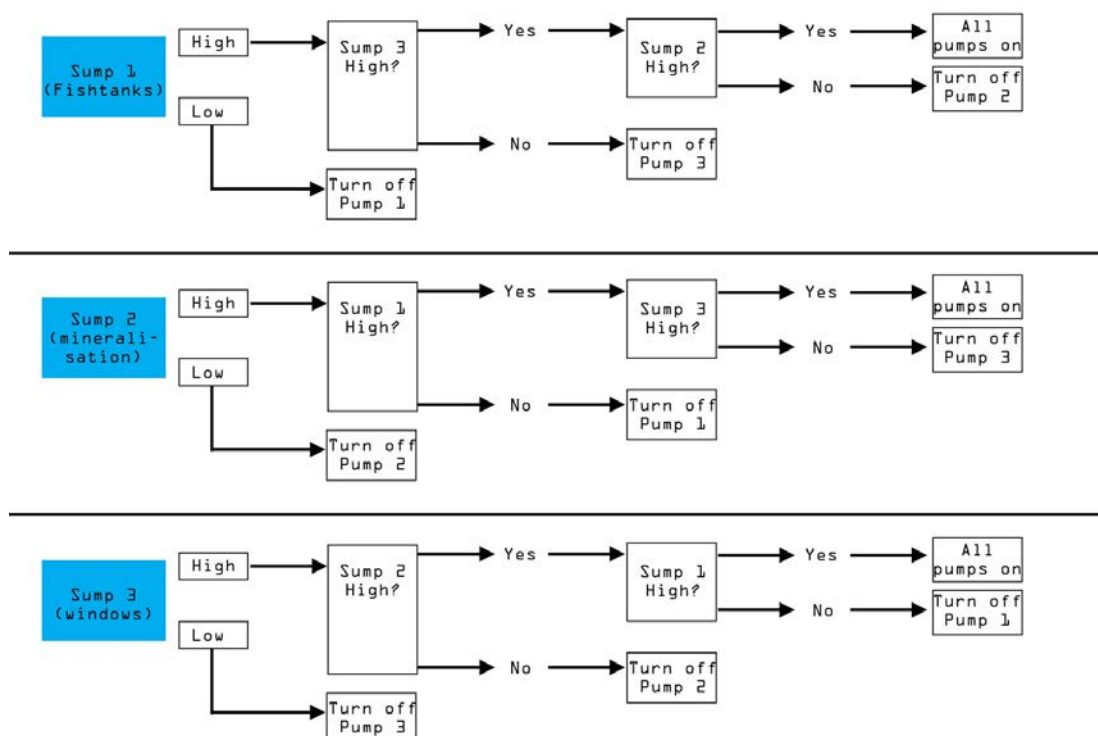


Figure 5.40 - Pump logic for the elevated aquaponic system

Finally, the temperature of the system is also an essential metric because it directly relates to the activity of the fish, which ultimately determines how much they eat, and, therefore, the availability of nutrients for crop growth. Hence, each tank was to be fitted with a temperature probe and a tank heater. The polytunnel was also equipped with a temperature probe so decisions could be made as to whether the temperature needed to be increased or decreased to protect the crops. The other probes that would be placed within the polytunnel to monitor its productivity would be a lux sensor, carbon dioxide probe and relative humidity probe. These probes would then feed back to a central controller and computer system and be distributed to a touchscreen to allow easy access to the information. At this point, the design of the elevated aquaponic system and monitoring system was finalised. The next step in delivering the project would be the detail design of the individual components as well as their construction.



Figure 5.41 - Visualisation of the final design showing polytunnel on the roof, fish tanks, filtration unit and window systems on the second floor along with lecture space on the first floor

5.3.9 - Detailed design and construction

The detailed design of the system was split into five sections of work; the aquaculture lab, the filtration unit, the window systems, the NFT system and the piping design that connects everything together. The detailed design of the individual elements of the system would address objectives such as universally supporting the tanks across the length of each beam as part of the aquaculture lab, designing an efficient filtration system and the effective suspension of the growing bags in the windows, to name a few. The plumbing portion of the detailed design phase would address the design of the fish tanks and the size of pipes at different locations throughout the system as well as their individual connections. A brief description of the design and construction of each element of the elevated aquaponic system is given in the proceeding pages with a few images documenting the construction process.

Aquaculture lab - Second-floor

The aquaculture lab is the hub of the elevated aquaponic system, and it is the structure that both supports and envelops the fish tanks to create a crisp white cube within the space. The aquaculture lab is 8.9 metres long, 7.1 metres wide and 2.4 metres high, with regularly spaced apertures along each side to be able to view each fish tank. The fish tanks, when filled with water, would weigh close to 850 kilograms, so it was imperative to distribute this load evenly along the length of the steel beams, which lay beneath them. This was achieved by constructing timber box sections that measured 74 centimetres wide, 86 centimetres high and either 5.7 metres long or 7.6 metres long. However, due to subsidence of the building's foundations over its lifetime, the floor had fallen by ten centimetres diagonally from one corner of the aquaculture lab to the other. To ensure the tanks were level and plumb, the timber box sections required extensive packing out. Two of these box sections would also contain sumps as part of their construction - made from six-millimetre plywood with a natural rubber lining - and collectively, the box sections would also support the four facades of the aquaculture lab. The fish tanks were 150 centimetres long, 75 centimetres wide, 75 centimetres high, and made from glass with a pre-cut hole to attach an outlet pipe to. The fish tanks sat upon specially formed insulated boards, which sat upon six-millimetre plywood boards, and would

be clad on all four side with insulation and be provided with an insulated lid when completed. Initially, it was intended that there would be an inclined plane at the bottom of the fish tanks to promote the movement of solid waste to the outlet pipe, which started at the base of the tank and looped up, through the pre-cut hole and down into the sump beneath. However, the outlet pipe performed so well during testing that it was not deemed necessary during construction to add the mesh and inclined plane. The exterior of the aquaculture lab was constructed from a timber superstructure and clad with plasterboard. The aquaculture lab also included a touchscreen, which interfaced with the control systems. The touchscreen would display the metrics identified earlier such as fish tank temperature, flow rates and pH, to name a few. Finally, a grey kickboard was added at floor-level to help hide the slope in the floor and complete the structure.

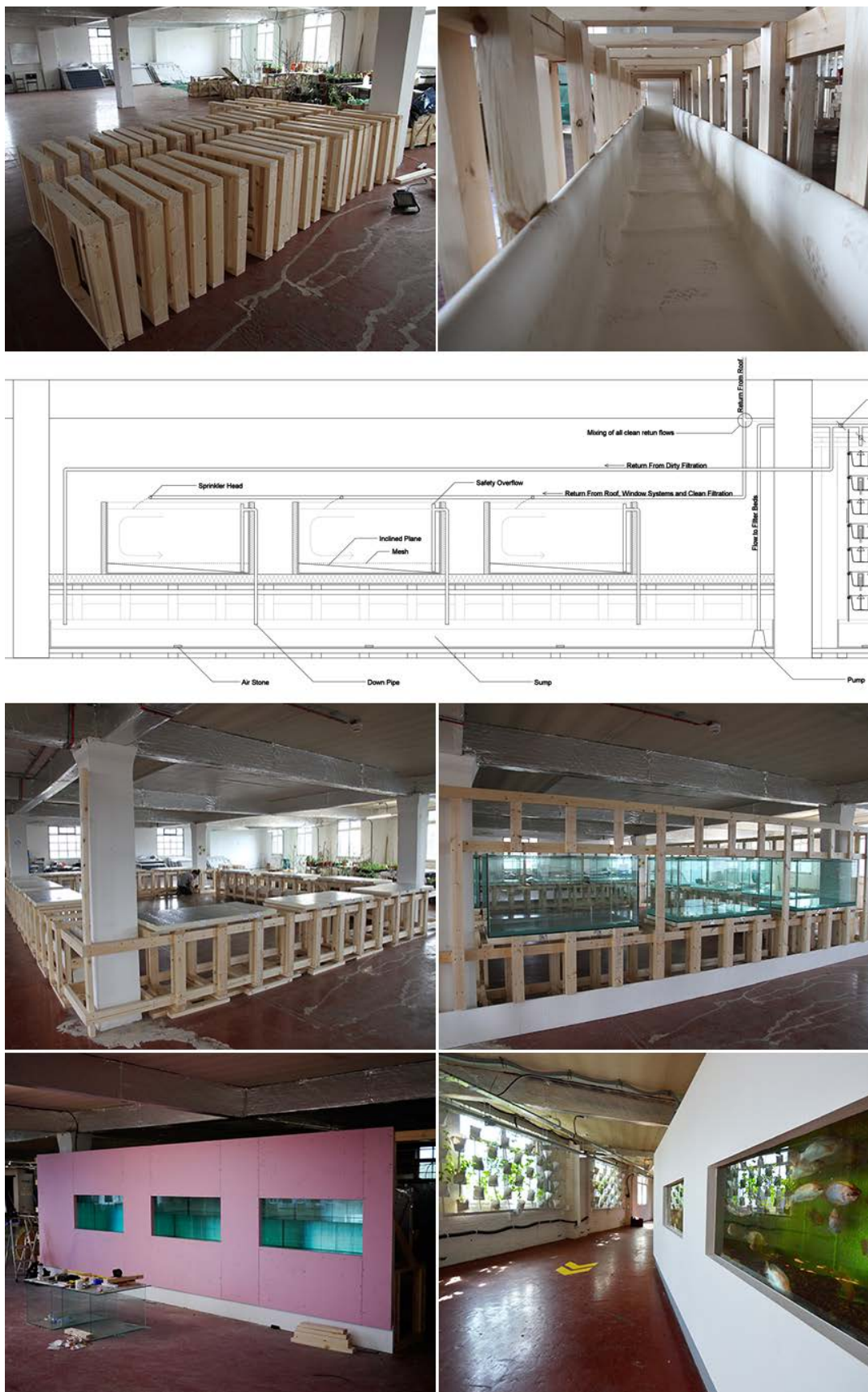


Figure 5.42 - Construction of the aquaculture lab (See Appendix I for full sized images)

Filtration unit - Second-floor

The filtration unit was the first element of the system to be constructed. Made from 10 centimetre by 5 centimetre planed and square edged timber, the filtration unit was a basic timber box section that was 7.6 metres long, 74 centimetres wide and 2.4 metres high. Within the timber box section were ninety-eight bright green washing up bowls, suspended from a threaded bar and held in place by aluminium u-section profiles. The washing up bowls would hold the expanded clay balls, which would act as the main site for biological and mechanical filtration; i.e. the filtration of chemical and solid waste. Each washing up bowl was fitted with a syphon - made from 5 centimeter ABS external pipe and a 1 centimetre internal pipe - which would allow the bowl to fill with water - maximising the contact between the water and the bacteria - and then drain again promoting oxygenation of the bacteria. The addition of a mesh cylinder around the syphon would stop the downwards migration of expanded clay balls and the clogging of downpipes as well as allowing the syphons to be accessed and maintained without affecting the media. At the bottom of the filtration unit was a sump - similar in design to those beneath the fish tanks - which was constructed from 6 millimetre plywood and lined with natural rubber. Where possible, natural and inert materials were preferred as it was important to utilise materials that would not leach chemicals into the aquaponic system. Hence, glass was utilised for the fish tanks instead of acrylic, and natural rubber was preferred in comparison to other toxic alternatives. To maximise the efficiency of the filtration unit, air stones were placed in the bottom of the sump. These porous mineral disks, when connected to an air compressor, produce very small air bubbles which would maximise the diffusion of oxygen into the water supply. This would further increase the number of aerobic bacteria that could continue to biologically filter the water within the sump, as well as improving the overall oxygen level of the water supply, which is good for both plants and fish. To complete the filtration unit, the timber structure was painted white and clad with polycarbonate roofing sheets. A grey kickboard was also added to the bottom of the filtration unit to help visually tie in the filtration unit with the aquaculture lab. After the festival the filtration unit would be populated with worms to help with the efficient breakdown of the solid waste from the fish, maximising the nutrients that could be made available to the system.



Figure 5.43 - Construction of the filtration unit (See Appendix J for full sized images)

Window systems - Second Floor

The window systems occupied five of the eight south-facing windows on the second-floor of Irwell House. Each window system consisted of thirty silicone grow bags, which were suspended from the steel lintels that were fitted to the building to help support the additional loading of the roof. The depth of grow bags would allow a more varied range of crops to be grown within the elevated aquaponic system such as tomatoes, peppers and chilli peppers, which have large root systems and need good anchorage. Unlike the sumps of the aquaculture lab and filtration unit, natural rubber could not be utilised for the construction of the grow bags because rubber is not UV stable, and would eventually deteriorate due to exposure to sunlight. The silicone bags were cut from a large silicone roll and constructed using specially formulated silicone glue. This would include wrapping the silicone around itself to form a cylinder and gluing it along the back, placing a length of pipe within the grow bag and then pinching it together at the bottom to form a wedge. The use of a pipe between each grow bag would allow the water to percolate through the window system, whilst minimising the risk of splashing. This would not only reduce the water that could be potentially lost from the system, but it would also minimise the risk of people slipping. Once the bags were constructed and suspended, they were then filled with media, which not only provided anchorage for larger crops but would also boost the biological and mechanical filtration within the system. It was later discovered that the placement of the media directly into the silicone grow bags made them very difficult to clean. This is because it was difficult to extract the media from the grow bag by hand, due to the fact that the grow bags could not be removed from the galvanised wires that they were suspended from. Hence, the design of the grow bags was amended at a later date to include a mesh insert. This would allow all of the media to be removed in one go when the mesh bag was lifted from the grow bag, which made the cleaning and harvesting much more efficient.

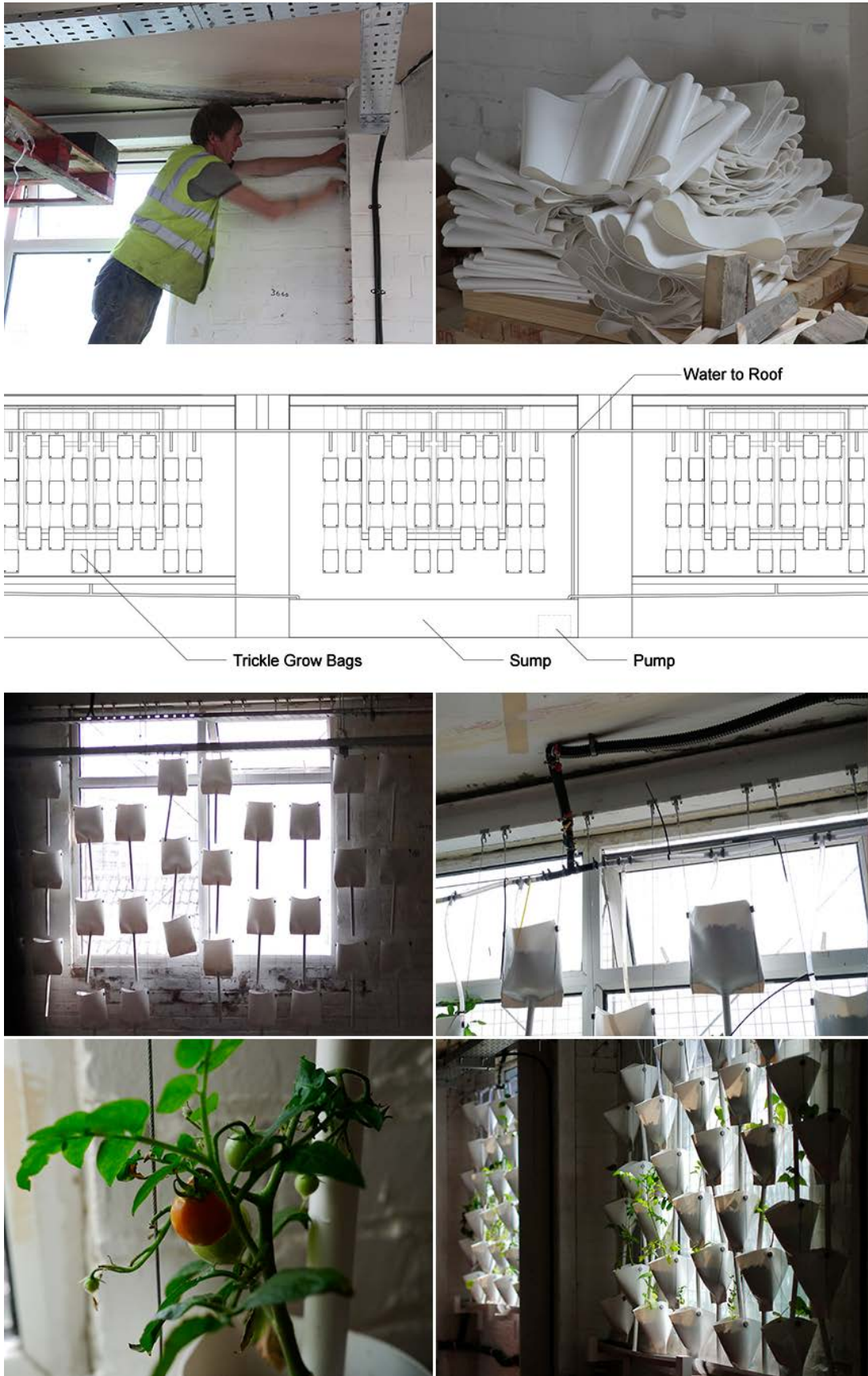


Figure 5.44 - Construction of the window systems (See Appendix K for full sized images)

NFT system - Rooftop

The placement of the NFT system on the roof was dependent on the construction of a larger polytunnel that would both envelop it and protect it. As previously discussed, the polytunnel sat on two steel transfer beams, which allowed the force of the polytunnel - and the forces that acted upon it - to bypass the weak roof and tie directly into the structural frame of the building. The polytunnel was bought as a kit and measured 15 metres long, 7.5 metres wide and 2.9 metres high. The NFT growing channels were grouped into four banks based on the maximum reach a person would have, which was agreed to be approximately 80 centimetres.

Therefore, the two smaller banks of NFT growing channels, placed on the periphery of the polytunnel would be a maximum width of 80 centimetres, whereas the two central banks would be a maximum of 1.6 metres wide because they would be accessible from both sides. The growing channels would be made from a combination of 11.5 centimetre PVC house guttering and 13 centimetre electrical trucking covers. The smaller banks of growing channels would contain six lengths of guttering, giving a total width of 78 centimetres, and the larger banks would be constructed from eleven lengths of gutter, giving a total width of 1.43 metres. In the previous chapter, it was noted that the recommended length of any NFT channel should not exceed 15 metres, to avoid nutrient falloff along the length of the channel. Due to the length of the polytunnel being 15 metres long the NFT banks to the periphery of the polytunnel were constructed to be 14 metres in length because they did not require access at the foot and head of the channels, and the central larger banks would be constructed to be 13 metres in length because access was required at the foot and head of the growing channels. The growing channels were made from two-metre sections of gutter, which were connected using readily available and standardised guttering components such as bridge connectors and stop ends to ensure that each channel was water tight. Much like the aquaculture lab and the filtration unit, the NFT system was supported using 10 centimetre by 5 centimeter planed and square edged timber. Supporting legs and cross members were constructed at one-metre intervals to ensure the plastic gutters were sufficiently supported to avoid bending and pooling of water, and to minimise the use of materials to ensure the NFT system was as light as possible. The timber supports gradually shortened along the length of the NFT system to provide a fall of 1 metre in every 50 metres. This would ensure the water flow was slow enough for sufficient

for nutrient uptake but quick enough to minimise the weight of water on the roof and to minimise pooling where solid waste might collect. The conduit trunking lids were drilled with a hole saw to create the openings into which the cages that would hold the crops would be placed. The trucking lid helps to support the crops from above whilst minimising the opportunity for water to evaporate out of the system. At the very end of each growing channel, a small growing cage was placed to trap any debris before the water returned to the fish on the floor below.

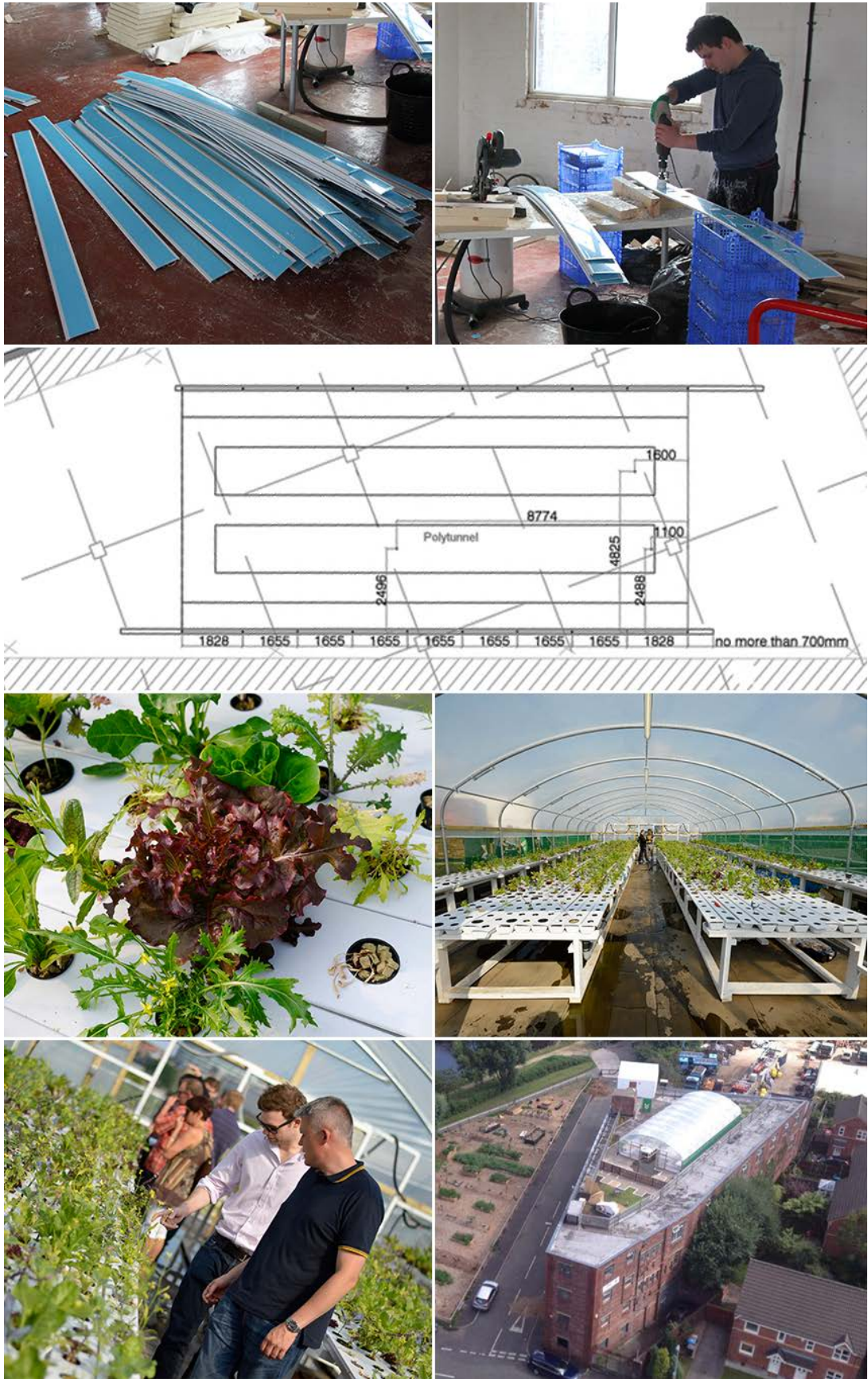


Figure 5.45 - Construction of the NFT system (See Appendix L for full sized images)

Plumbing and pipework

One of the more complex aspects of the elevated aquaponic system was to determine how water would be moved from one element of the design to the next. It was of paramount importance to ensure sufficient pressure across the system whilst ensuring water tightness to minimise water loss and the possibility of water ingress of the building's structure. This was a truly extensive task and resulted in the use of over one thousand individual components and over 250 metres of pipework. The primary difficulty, in most instances, was ensuring the successful stepping of components to ensure water pressure. An example of this was the successful delivery of water to the 34 NFT channels on the roof from the sump of the window system. The pump within this sump not only had to pump the water over four metres high, but it also had to push the water out of sixty-eight outlets at roof level; i.e. two outlets per NFT channel. The method employed to tackle this was to ensure that the cross-sectional area of pipework was always the same, no matter if there was one pipe or sixty-eight pipes. This led to the natural reduction in pipe diameter as the pipework moved further away from the pump and separated to feed different elements of the system, which ensured water pressure. As a failsafe, and where possible, most outlets were fitted with a valve that allowed water pressure to be better balanced across a single element of the elevated aquaponic system. This was very useful if, for example, one of the window systems was receiving the lion's share of the water supply. In this eventuality, the valve at that location could be closed slightly to increase flow to the other window systems. These strategic valves were located at the top of each column of filtration bowls, at the head of each window system and the beginning of each bank of NFT growing channels on the roof. Many consumer pumps have a built-in valve which allows the power to be throttled back if required but due to the volume of water that needed to be pumped around the system, commercial grade pumps had to be purchased. In addition to this, there were some other plumbing design decisions that would make for a more user-friendly system. For example, the outlet pipes of the fish tanks had a section of pipe rising out of the water that was open to the air. This primarily stopped the outlet becoming forming a syphon; draining the tank unintentionally and killing the fish. However, the creation of a syphon can be beneficial in the instance where a tank needs to be emptied for cleaning. Therefore, a bung was fashioned that could be placed in the top of the outlet pipe, which would allow the tank to drain without the

need for additional pumps. Similarly, the returning water from the roof, which was distributed evenly to each fish tank, could also be stopped on a per tank basis. This would allow tanks to be emptied without water re-entering from above during the cleaning process and would also allow tanks to be quarantined if there was an outbreak of disease. For a full list of all the components used, please refer to the detailed specification contained within Appendix O.

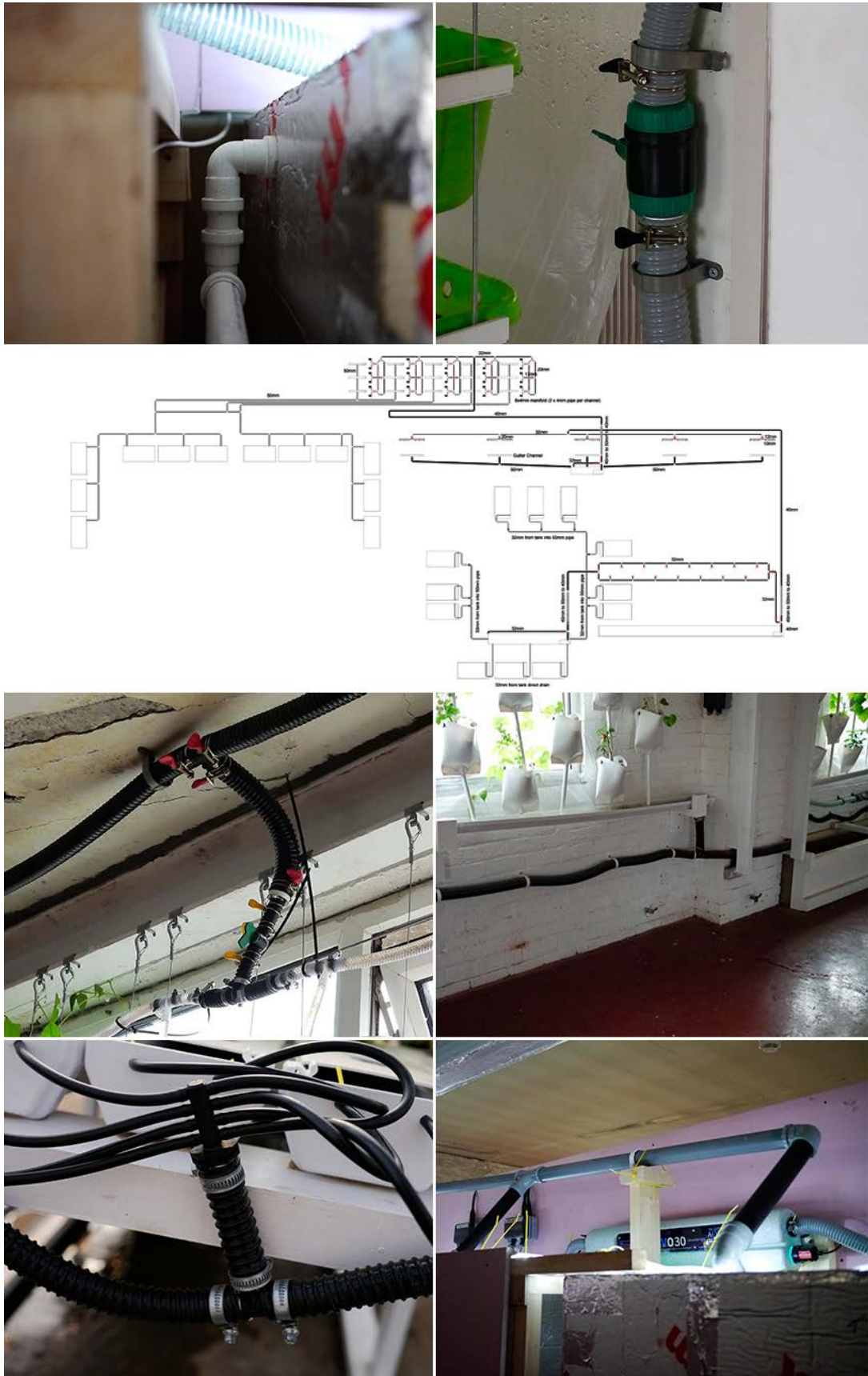


Figure 5.46 - Examples of plumbing and pipework (See Appendix M for full sized images)

5.3.10 - Legionella

The health and safety of those visiting the project and those that would later run it was of paramount importance in the development of the elevated aquaponic system. Early on in the project, the design team were made aware that although a low risk, legionella could develop in the system, which could then be contracted by those in contact with, or near to, the elevated aquaponic system. Legionnaires' disease, also known as Legionellosis, is an infectious disease caused by bacteria belonging to the genus *Legionella*. Over 40 species of *Legionella* bacteria have been identified, although only a handful are known to cause infections in humans. The primary risk within recirculating water systems is *Legionella pneumophila*; an organism primarily found in cooling towers, air conditioners and other water systems. *Legionella* bacteria are natural inhabitants of freshwater systems such as ponds, streams, lakes, rivers, soil, and mud, and can thrive in warm, moist conditions. *Legionella pneumophila* can be transmitted via inhalation of water droplets in aerosol form, which can potentially lead to Legionnaires infection. The risk of developing Legionnaires disease increases when people are exposed to infected environments created as a result of recirculating water systems, such as aquaponics, or when immune deficiencies are present. Infection from person to person, or from animals to person, does not occur. As part of the handover process, a full legionella risk assessment was carried out which can be seen in Appendix O.

The proliferation of *Legionella pneumophila* in water systems is the result of interrelationships between temperature, environmental microorganisms, sediments, and the chemical composition of water. The risk of contracting Legionnaires' disease can be reduced to a very low level of risk through the careful design, installation and regular maintenance of aquaponic systems and by the reducing the potential sources of water aerosol. The proliferation of *Legionella* is known to be promoted by wet, warm environments (20°C - 45°C), water stagnation or slow moving water, high microbial concentration - including algae, amoebae, slime and other bacteria - the presence of biofilm, scale, sediment, sludge, corroded materials or other organic matter, and degraded plumbing materials, such as rubber fittings, which may provide nutrients to enhance bacterial growth. Maximum growth of the bacteria occurs within the temperature range of 35°C - 43°C. Environments of 50°C or higher temperatures are sufficient to kill the bacteria.

An aquaponic system is a closed recirculating water system that encourages the growth of certain bacterias and creates opportunities for temperature fluctuations. Any environment or piece of equipment with the potential to create water aerosols has the potential to transmit the disease if the water is contaminated with Legionella. Therefore, the risk of Legionella growth and contamination had to be considered. The key areas of concern within the system are identified below, along with their level of risk - i.e. low risk, moderate risk, and high risk - and the possible actions that could be taken if required.

Water temperature

The water temperature of the system was considered low risk because the water would be maintained at a temperature between 12°C - 16°C, which is below the specified temperature zone for Legionella bacteria growth. In addition to this, the water temperature was monitored continuously by the control panel provided by Siemens. If the water temperature reached 20°C, a water change will be conducted to reduce the temperature, and water samples will be taken for testing. If the water temperature was to reach 25°C, the whole system would be shut down, and further samples would be taken for testing.

The presence of stagnant water

The risk of stagnant water occurring in the aquaponics system was low. A constant flow of water is crucial to the productivity and efficiency of the system and as such the system was designed to encourage a continuous flow of water. All pipes within the system were laid to falls to promote the movement of water and to eliminate the possibility of stationary water within the system. The water within the system was cycled at a rate of 9000 litres per hour, resulting in a full water change per fish tank, per hour.

Sediment build up

The risk of sediment build up in the aquaponics system is moderate. Solid fish waste is held within the system to be utilised as an eventual nutrient source for the crops. The fish waste is, therefore, encouraged to move around the system, through the

use of powerful pumps, where it is broken down and ionised, reducing the risk of sediment build up.

The potential for aerosol formation

There are two particular areas of the aquaponics system that can be identified as a moderate risk for the formation of aerosols; i.e. the filtration unit and the window systems. These elements both rely on the flow of water between containers, which increases the chances of splashing and possibly the formation of aerosols. To minimise this, the filtration unit was fitted with a clear plastic sheet on both sides to ensure any splashing was kept within the bounds of the filtration unit. Additional pipework was also installed on the bottom of every syphon to ensure splashing was reduced to a minimum. The window systems utilise long lengths of pipe at the bottom of each grow bag, mentioned previously, to carefully guide the water falling through the window system to the next bag without splashing.

Legionella filtration

Inline UV filtration units were incorporated into the design of the aquaponic system to further reduce the risk of Legionella growth. Three UV filters were placed after the high-risk areas in the system; i.e. after the fish tanks, after the filtration unit and after the window system. This would not only kill the Legionella bacteria as it passed through the filter, but it would also stop Legionella bacteria moving through the system and colonising in other areas if it was present.

Legionella testing

A water testing regime was also put in place to ensure Legionella activity was continually monitored and recorded. These tests were to be carried out by a suitable and relevant professional body, which forms part of the detailed Legionella risk assessment in Appendix O.

5.3.11 - Commissioning the elevated aquaponic system

The commissioning of the system was the final stage of the delivery of the elevated aquaponic system that formed part of the Biospheric Project for the Manchester International Festival 2013. Due to the time and effort that had been put into the design and construction of the system, the commissioning of the system was relatively straightforward. Firstly, the system needed to be tested as a piece of technology before any living things were added to it. This included the testing of all the individual elements, as well as checking for leaks, balancing the system and ensuring there was sufficient pressure across the different elements of the design. The system was gradually brought online by first testing the aquaculture lab, then the aquaculture lab and the filtration unit, then the aquaculture lab, filtration unit and window system and finally the aquaculture lab, the filtration unit, the window system and the NFT system. There were leaks in the early stages, and these were remedied quickly, but there were also floods. The balancing of the system had been more complex than first expected and as such the movement of water was not equal between the three sumps in the system. At this point, the control system from Siemens had not been delivered to site, but it was imperative to start cycling the system to give the system enough time to mature before the fish were added. Hence, the decision was made to ensure that one of the sumps was always receiving more water than it was pumping away, into which a bilge pump would be placed. The bilge pump would turn on when the water within the sump reached a specific height. This bilge pump would be located in the sump associated with the window system and would ensure the safe running of the system until the control system was up and running. When the monitoring system was brought to site, it remedied this problem immediately through the use of the high-level, and low-level switches in conjunction with the pump logic discussed previously.

The last phase of commissioning the system was the introduction of the living organisms. By this point, the elevated aquaponic system had been cycling for a few weeks, giving plenty of time for sufficient level of bacteria to colonise the filtration unit and window systems through the incremental addition of ammonia to the water. The two species of fish to be added to the system would be tilapia due to its hardy nature and fast growth rates, and carp, due to it being a hardy native species. So as not to put too much strain on the filtration of the system the two fish species were

added to the system at different times. The tilapia were added to the system first, and the carp were added later. Finally, the very last task was to add the crops to the system, which included the planting of the larger crops, such as tomatoes and peppers in the window system, and the placement of leafy crops such as lettuces and chard into the NFT system. At this point, the system was officially completed; proving that a heavy aquaponic system, along with all the benefits that come with it, can be integrated above ground-level within an old existing building regardless of its condition. This gave a great sense of achievement to the design team and all those who helped to construct it, along with an improved understanding of what the future of urban farming might look like.



Figure 5.47 - Panoramic photographs of (from top to bottom) the aquaculture lab and filtration unit, the NFT system, and the polytunnel on the roof

5.4 - Conclusions of the elevated aquaponic system

The design, construction and commissioning of the elevated aquaponic system was a ten-month engagement between Manchester International Festival 2013 and

Queen's University Belfast that delivered a highly complex and ambitious project on time and on budget. The design of the system was a compromise between the conflicting needs of the project to perform as both a food production facility, exhibition, living lab, and community resource. Due to this, the system was partially contained on the top-floor of Irwell House and partially upon the roof, where light levels were highest. The aquaculture, filtration and window systems were contained on the second floor of the building, with the roof space housing the large NFT system that was located within a large polytunnel. The design team worked closely with structural engineers, aquaculturists, botanists and gardeners to delivery a structurally and ecologically sound urban food system within an existing building that was in a poor state of repair. The delivery of the project, however, would not have been possible if it was not for the hard work and determination of local volunteers and volunteers from Queen's University Belfast. The design of the elevated aquaponic system was a complicated undertaking and the following sections document the challenges that faced the delivery of the urban farm, along with the inputs and outputs of the system, the process of handing over the system, future adaptations relating to the design, opportunities for public engagement and a summary of the knowledge acquired.

5.4.1 - Problems encountered

The primary technical difficulty faced during the development of the project was the structural limitations of the building, which defined many of the design decisions made early on in the process. The structure of the building - much like any building for that matter - was not designed with the intention to support the additional loads associated with the elevated aquaponic system; estimated to be approximately 15 tons in total. The beam and block construction of both the roof and the intermediate floors was only capable of supporting approximately 150 kg/m² and 350 kg/m² respectively; neither of which would have been capable of supporting the fish tanks that weighed over 500 kg/m² when full. This lack of structural capacity was compounded by the fact that the project also had to function as an exhibition space, which would require spare structural capacity to support the weight of people walking around the system at any one time.

This discovery drastically altered the approach to the design of the elevated aquaponic system and made the design team think carefully regarding the placement of the different elements of the system. Through structural investigations, it was found that there was additional capacity within the steel frame of the building, which was a lifeline for the project. This allowed the heavy elements of the system, such as the fish tanks and the filtration unit, to be placed directly above primary steel beams, thereby eliminating any engagement with the weak beam and block floor. Minor structural alterations were required to support these heavy elements, which simply included the welding of stiffener plates in between the flanges of the cleats that connected the beams to the columns. In some instances, more robust structural alterations were required to ensure the structural integrity of the building. With regards to the placement of the polytunnel on the roof, the two steel transfer beams had to be physically connected to the steels that supported the roof. This resulted in the roof being broken out at the points of connection to allow the transfer beams to be physically clamped to the steel frame beneath. In addition to this, steel lintels were also required to support the edges of the roof, where the original concrete window lintels had failed.

The structural considerations that were required to integrate the aquaponic system within the building at second-floor level were by far the biggest challenges to overcome in the project. However, these issues were not the only challenges that faced the integration of the system. During the development of the aquaponic system, it was evident that the flooding of the building was also a probable risk that needed addressing. The risk of flooding was reduced through the introduction of valves and backflows to help better equalise the flow rate across the three pumps, as well as the development of the control system and pump logic - specified by QUB and realised by Siemens - that would manage the pumps automatically. Unfortunately, before the delivery of the control system from Siemens, there were occasions when the sumps overflowed, which led to the flooding of the building. In some instances, these floods were quite large, especially if they occurred during the night, and were able to track through to the floor below. These challenges were overcome to a certain extent through the delivery of the control system, however, the flow metres that were fitted to determine flow rates and breaches could only be connected to large-diameter sections. Therefore, if any leaks or breaches occurred after this point in the system, it would be some time before the level of water

dropped in each sump to a sufficient level to stop all the pumps. Although these issues were identified early on as risks, it was only ever the sumps that overflowed before the delivery of the control system, and no pipework ever breached. There were slight drips that occurred during commissioning but the fitting responsible were either tightened or wrapped in plumbers tape to resolve the issue.

The final challenge faced with regards to the implementation of the elevated aquaponic system was the risks posed by the development of *Legionella* within the system. This was a risk that was not brought to the attention of the design team until during the construction phase of the aquaponic system. To combat these risks, the design had to be amended slightly to minimise splashing and the creation of aerosols and to restrict the splashing water to particular areas. Operational and maintenance duties also had to be imposed to ensure the safe running of the system.

5.4.2 - Inputs and outputs

Due to the symbiotic nature of aquaponic systems, the inputs to the system were very simple because it only required water, fish food and electricity to function. The largest input to the system was the initial filling of the system. This required that all the fish tanks were filled and all three sumps were filled. In total, this required 13,750 litres of water initially. Based on recent prices published by United Utilities, who are the primary water provider for Great Manchester, the cost for one thousand litres of water is £1.78. Therefore, the cost of this initial fill was £24.50. Based on a top-up to the system in the region of 1,000 litres per month, this would bring the total cost of water to £44.50 per annum, due to the system being emptied once a year for a deep clean. The food input to the system was approximately two percent of the total weight of the fish per day, which was calculated to be approximately £1 per day. Therefore, £360 per annum would have been spent on fish food. The three water pumps created the largest demand for electricity use within the system, which collectively required 2.5kwh to continually move the water around the system. Based on a cost of £0.15 per kWh, the pumps would use £3,240 per annum. However, the addition of solar panels to the roof, which was allocated an area along the entire south-east edge of the roof, would reduce this cost to varying extents throughout the year. Unfortunately, these were never installed due to budget constraints and

therefore the demand for electricity from the grid remained the same. The total running costs, therefore, would be £3,644.50 per annum; with electricity accounting for nearly ninety percent of these costs. In addition to these annual inputs and costs, the delivery of the system would also depend on the upfront costs associated with the equipment and the living things that brought it to life.

The total cost of the system, including all the structural alterations, but not including the cost of labour, was approximately £28,500; please see Appendix N for the full cost breakdown. Although this is a significant sum of money, it would enable the production of approximately 16,500 crops per annum, which based on the assumption of four harvests per year, could generate £33,000 in sales. This estimated value is calculated utilising the sale price of crops in the food shop that was also commissioned as part of the Biospheric Project in an adjacent residential tower. The shop was located less than one hundred steps away from the elevated aquaponic system, and it would be a point of sale for the food produced by the project. It was agreed that the crops would be sold for £2 each, due to the innovative methods that were used to grow the crops, their improved freshness, and the short distance they travelled from harvest to point of sale. The cumulative area of the building utilised to grow these crops, inclusive of the area taken up by the system and the area required to access the system, was 154.7m². This gave a productivity value for the elevated aquaponic system of 26.66 crops per square metre, which based on four harvests per year is just over one hundred crops per metres squared per annum. Based on the above numbers, it can be seen that initial investment could be recouped within the first year, after which the system would be profitable to a certain extent, dependent on the wage paid to the primary operator of the system. The elevated aquaponic system was designed to need only one person to operate it on a day to day basis, and a full operational manual was produced by QUB to aid in the handover process after the festival concluded.

5.4.3 - Handover

The process of handing over the system to a named individual was a crucial phase of the research, not only because it ensured the continuity of the system after the departure of QUB, but also because it signified the process by which the community would take control of their urban food system. This was achieved through the use of

two key components. Firstly, a thorough manual for the system was written (see Appendix O), which included a maintenance schedule for daily, weekly, monthly and annual tasks, an operations guide, a husbandry guide for the fish, hens, bees and crops, and future recommendations for the system. Secondly, an extensive training session was organised to provide an opportunity for the design team to talk the future operator through the entirety of the system from start to finish. This included such training as what needed to be done before the system could be switched off, how to safely unblock a pump if it was to become obstructed, and how to clean the polytunnel without causing damage. The record of this training can be found in Appendix P. The handover process was an interesting characteristic of the project as it allowed an opportunity to explore how building integrated technical food systems may be procured in the future.

5.4.4 - Future adaptations

Although the elevated aquaponic system was a success and negotiated all the challenges that opposed its completion, it brought up serious questions as to whether this type of food system should be contained within buildings in the future. Technological food systems do not only take up space within buildings that could otherwise be utilised for office or residential purposes - generating income as a result - but they also create serious issues relating to the presence of water. These issues primarily include water ingress of a building structure - as a result of pressurised and unpressurised plumbing - and the creation of humid environments that can lead to the degradation of internal spaces if not ventilated correctly. Although not necessarily an issue for the elevated aquaponic system, the placement of food systems within buildings would also have to overcome drastic reductions in natural light capture that would otherwise need to be subsidised with artificial light.

There are some future adaptations that could, in some way, help to remedy these issues. The tanking of internal floors, for example, could be utilised to ensure that any water that did leave the system through flooding or leaking would not pose any danger to the building's structure. This would include the use of a water-resistant material that would be applied to the floors and partially up the walls to create an impervious barrier to the movement of water. This would also require the raising the height of door thresholds to stop water from escaping beneath existing doors. This

would indeed have a cost associated with it but this strategy would prevent any water damage to the building. In addition to this, technological food systems could be compartmentalised and ventilated appropriately, to restrict the creation of humid environments within buildings. However, the placement of key equipment will always be determined by the structural capacity of the building, which might not always coincide with the efficient use of specified compartments.

Ultimately, the decision to position technical food systems within existing buildings results in several challenges that would not need to be overcome if the location of future urban food systems were to be restricted to the building envelope: i.e. facade and rooftop. The exterior envelope of a building is designed from the outset to be water resistant. Hence, any floods from a roof-based or facade-based food system would be no different to that of a large downpour of rain. Also, any issues relating to humidity would no longer be an issue because the rooftop or facade-based food system could be ventilated sufficiently to provide the best environment for crop growth. This strategy of future urban food production would not only protect the interior the building from damage but it would also free up the internal space of the building to function as originally designed: i.e. as office or residential space, maximising the profit that can be generated from the building. Therefore, the only adaptation that would be considered for any future elevated aquaponic system would be to design the system to be located entirely on the roof, where issues relating to water ingress, humidity and loss of floor space are not an issue, and access to natural light is greatly improved; removing the need for artificial lighting.

It has been discussed throughout this chapter that roofs are not typically constructed to support even the weight of raised beds, let alone the weight of heavy aquaponic systems. However, through the use of transfer beams and transfer floors, it is expected that it would be possible to locate an aquaponic system on the roof of an existing building. It should be noted, however, that this recommendation to place urban food system upon buildings rather than within them, should be viewed as an 'initial step' at this point in time. That is to say that while building integrated technical food systems are in their infancy, it would be beneficial to reduce cost, risk and complexity, through facade or rooftop integration, to provide an easier route to market, minimising the need for artificial lighting or air handling units as a result.

5.4.5 - Public engagement

Throughout the project there had been many opportunities to engage with the general public. Many of the local population were very interested in what was happening inside the building and they all showed a genuine interest and excitement about the elevated aquaponic system. During the construction of the system, there would be volunteer days, where people from the local area could register to help out with the delivery of the elevated aquaponic system. In exchange for their much-needed help, they would learn about the aims and ambitions of the project, the nature of aquaponic systems and the designs for the completed system. Being a part of the project not only allowed people to contribute to something exciting that was happening in their local area but it also helped create a sense of ownership, as well as providing an opportunity for the design team to educate people on the issues urban agriculture is hoping to address in the future.



Figure 5.48 - Part of the design team with local volunteers

In addition to the volunteering days, there was also a further opportunity for the design team to engage with the local population; through the delivery of a two-part aquaponic workshop. Organised as part of the festival, the first session would focus of the differences between hydroponic and aquaponic systems, as well as the basic ecological principles, the filtration requirements and the growing techniques associated with aquaponic systems. The second session of the workshop included a guided tour around the completed elevated aquaponic systems and focussed on the construction of a window sill aquaponic system, which consisted of a fishbowl, a

funnel, some expanded clay balls, some mesh, a small aquatic pump, some gravel and a length of air line (see figure 5.49). All the participants were enthusiastic and asked lots of insightful question relating to both hydroponic and aquaponic food systems, and they were very excited when they were allowed to take their small aquaponic system home to start growing food; with the addition of a fish that they would introduce to the system after cycling it for a week first. Based on the enthusiasm of the general public during the construction of the elevated aquaponic system and the two-part aquaponic workshop, it is clear to see that technical food systems are considered engaging and worthwhile, which is hopefully a positive sign relating to public opinion and the integration of technical food systems in the future.



Figure 5.49 - Window sill aquaponic system constructed as part of the workshop

5.4.6 - Conclusions summary

In summary, the process of integrating a technical food system within an existing building has brought with it a wealth of knowledge. Primarily, this knowledge confirms that large aquaponic systems can be incorporated into existing buildings but also draws attention to the role structural capacity will have on the placement of technical food systems within or upon buildings in the future. The successful integration of the elevated aquaponic system also identified how building integrated technical food systems can negotiate multiple floors and provides a glimpse into what the future of urban farming might look like. However, as mentioned previously, the placement of future urban food systems may be more appropriately placed on the rooftops or facades of existing buildings, to alleviate the issues relating to water ingress and increased humidity within buildings, while maximising access to natural light, reducing the need for artificial lighting, and improving productivity. Finally, the detailed account of the design and development of the elevated aquaponic system provides an insight into the integration of the system within Irwell House, as well as providing initial costs, running costs, resource use and productivity that others will be able to utilise when they embark on similar projects in the future. A summary of the procurement of the elevated aquaponic system can be seen below.

Aquaponic procurement

- 1. QUB invited to design technical food system as part of MIF 2013*
- 2. Development of concept design by QUB*
- 3. Appointment of QUB to design building integrated technical food system*
- 4. Design and construction of small-scale aquaponic system*
- 5. Design and development of elevated aquaponic system*
- 6. Appointment of BDP to aid with structural calculations and provide advice*
- 7. Detail design of individual components of elevated aquaponic system*
- 8. Appointment of Siemens to aid in the development of the control system*
- 9. Construction of the elevated aquaponic system*
- 10. Commissioning of the elevated aquaponic system*
- 11. Opening day of the Manchester International Festival 2013*
- 12. Handover of elevated aquaponic system*

5.5 - Facade-farm

During the development of the elevated aquaponics system it became apparent that the components, chemistry and biology within the system were all scalable - i.e. the conversion of ammonia to nitrate would occur naturally regardless of the size of the system. Hence, the elevated aquaponic system could be redesigned to occupy a small window sill or an entire city depending on the context in question. The scalability of aquaponic food systems, along with the future adaptations noted above - i.e. that technical food systems may be best placed upon the surface of buildings as opposed to within them - led to the notion that an aquaponic system could be located within the cavity of a double-skinned facade. This led to the concept of a 'facade-farm'; a double-skinned facade that was capable of growing crops and fish within its cavity while generating an economic return from a building component that would otherwise cost money to maintain. The implementation of such a facade would not only aid in further improving the food security of cities, in addition to such initiatives as the elevated aquaponic system, but might also help minimise the energy demand of buildings through the environmental mediation provided by not only the double-skinned facade but also the plants within the cavity; decreasing the need for traditional air conditioning systems as a result.

5.5.1 - Facade-farm conception

The development of the facade-farm started in the same way as the larger elevated aquaponic system; with the understanding that the fish produce waste that is converted into available nutrients through biological filtration, which is then utilised by crops for growth. The only difference between a facade-based aquaponic system and a floor-based aquaponic system is that the elements would have to be stacked vertically to fit within the cavity created between the two glazed surfaces (see figure 5.50). The conceptual development of the facade-farm was based on a clear differentiation between the hardware - i.e. the technical and mechanical components - and the software; i.e. the living things, such as fish and crops. The idea of the hardware/software interface, much like a computer, allows the software to be changed easily depending on the needs of the user and upgrades to be made to the hardware as and when required to increase efficiency and functionality. The notion that the facade should be capable of supporting numerous combinations of living

things as well functioning as expected regardless of global position, climate, culture or orientation, was a driving force behind the adaptation of the elevated aquaponic system into a vertical facade-based system. This adaptation would ultimately allow vertical aquaponic systems to exist in any part of the world, whilst simultaneously improving food security and minimising building energy use.

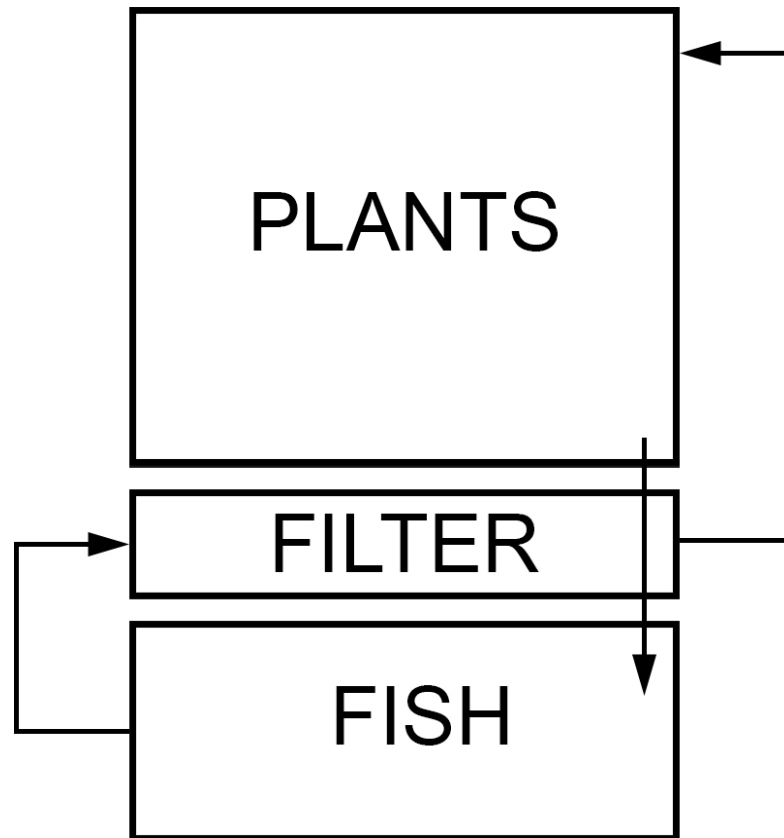


Figure 5.50 - Simple elevational schematic of the facade-farm aquaponic system

The design and development of the fish tank was relatively straightforward, due to its rectilinear form. The design and development of the growing system, however, was far more complicated undertaking. It was apparent, based on previous findings, that the method of crop production would have to be an NFT system - due to its low weight - but the arrangement of the NFT growing channels would have to be carefully considered to maximise crop production. The typical arrangement of NFT growing channels when stacked vertically is one upon another, such as the cascade NFT system seen in chapter 4.0. However, with a typical width of 100 millimetres to 150 millimetres, the NFT growing channels would not make full use of the depth of the cavity between the two glazed surfaces of the facade; i.e. the productivity of the

facade would not be maximised. It was, therefore, evident that the NFT growing channels would need to be at least two channels deep to make use of the space. This arrangement, however, would cause issues relating to overshadowing; i.e. one crop being in the shadow of another, leading to variable growth rates. In order to reduce the effect of overshadowing, the idea of a kinetic NFT system was entertained; whereby crops would be continually rotated, moving from the back of the cavity to the front, and vice versa, to evenly distribute access to sunlight.

This led to the idea of a conveyor-like aquaponic system, which would combine the methods of an ebb and flow system with that of an NFT system. The resulting combination of these two ideas is that the channels would be filled with expanded clay balls to provide the filtration for the system; completing one revolution every hour. As the channels moved around the cavity they would fill with water as they reached the bottom of the loop, and gradually drain as they moved around the system, providing nutrients to the other plants and oxygen to the bacteria. Such an arrangement would also allow the crops within the system to be harvested from inside the building via a small panel in the rear of the facades farm. The initial concept for the facade-farm can be seen in figure 5.51.



Figure 5.51 - Facade-farm initial concept

5.5.2 - Facade-farm prototype

During the development of the facade-farm, the Technology Strategy Board launched the Green Genius or 'Greenius' competition, which aimed to boost the government's green agenda at that time. It focused on environmental sustainability as well as sustainable ways of growing and providing food, with an emphasis on saving water and energy. The competition was potentially a perfect opportunity to build a working prototype of the facade-farm, and after the submission of the relevant forms and research proposals were made, the project received £50,000 to start work. The delivery of a working prototype would be a collaboration between Queen's University Belfast (QUB), Building Design Partnership (BDP) and Glassolutions; the largest processor, distributor, installer and repairer of glass and glazing systems in the UK. In delivering the prototype, Glassolutions would kindly provide a full-scale module of their VS-1 facade system; a self-supporting mullion only facade; QUB would design the aquaponic system within the facade, and BDP would analyse its environmental performance through the use of building energy modelling software. With the involvement of Glassolutions, the aquaponic system now had a context within which it could be designed. The VS-1 facade system was not a double-skinned facade so the second leaf would need to be manufactured separately. However, this would not be an issue for the first phase of the competition because the goal was simply to construct a proof-of-concept prototype.

Due to the financial limitations in producing the prototype and the short time-frame, it was decided that the NFT conveyor system should be replaced with one that was static. Due to this, the media within the NFT channels would also be removed and replaced with a purpose-built filtration unit. To better address the issues of overshadowing noted previously, the prototype would utilise an arrangement of NFT growing channels that would form a double helix, which would also maximise the productivity of the system. Based on the facade module provided by Glassolutions, this arrangement would provide 21.6 metres of NFT growing channel - i.e. 2 no. runs of 10.8 metres - and would be capable of growing 112 crops at any one time when planted at 200 millimetre intervals.

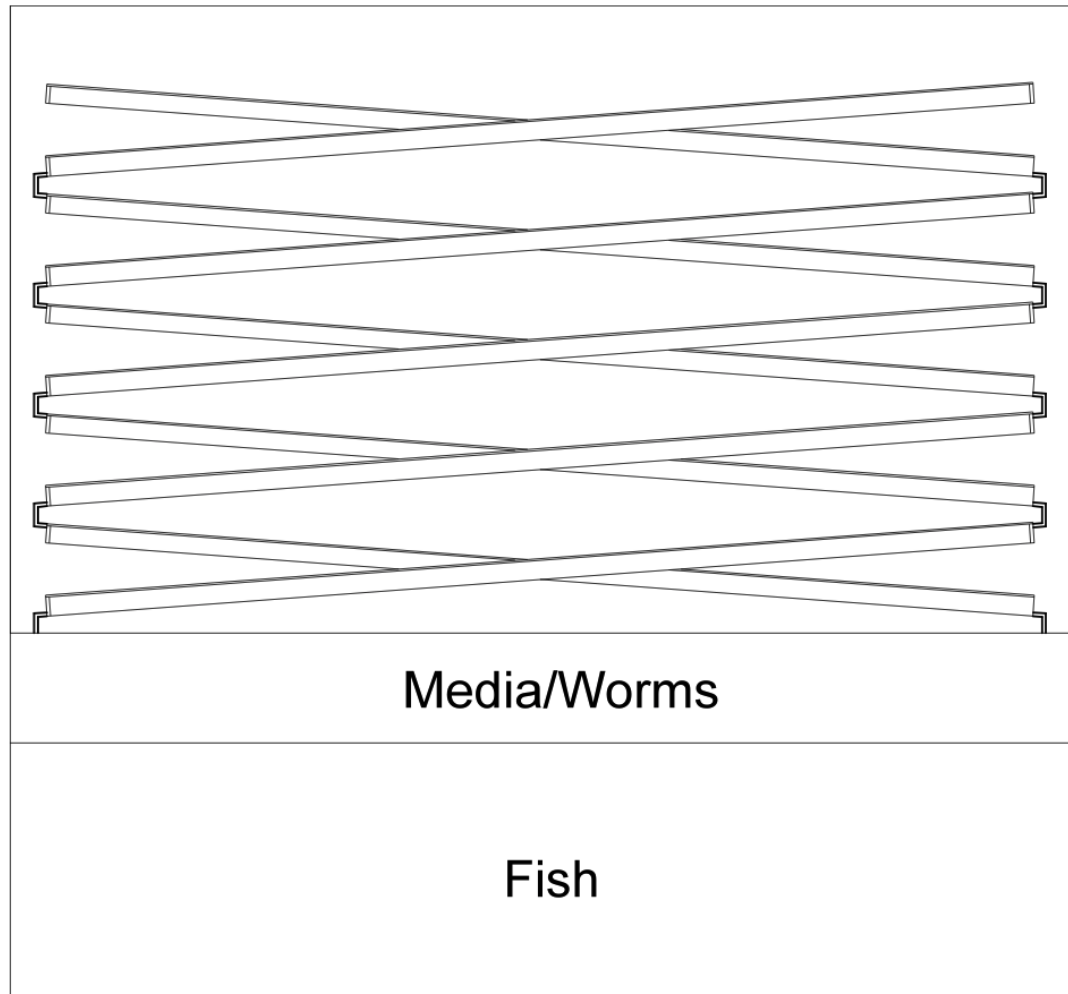


Figure 5.52 - Facade-farm static variation

The first constructed facade-farm prototype built upon all the knowledge gained whilst designing and constructing the elevated aquaponic system - such as the maximum length of NFT channels, the relationship between fish, bacteria and crops, as well as knowledge relating to pumps and plumbing - that occupied a large proportion of an existing building and miniaturised it into a space that was 3 metres high, 2.5 metres wide and 0.35 metres deep. The cavity, created in between the two glazed surfaces of the double-skinned facade, was able to accommodate all of the components seen within the larger system, such as fish tanks, filtration unit, and growing channels, but only required two pumps to move water around the system. The first pump moved water from the fish tank, which was located behind three spandrel panels to reduce algae buildup and decrease temperature variation of the water, to the top of the six filtration beds. The water would then trickle through the

expanded clay balls and would fall into an ionisation tank, which is simply a highly oxygenated body of water that promotes the growth of further bacteria to help break down the solid waste. The second pump then moved the filtered water from the ionisation tank to the top of each run of the double helix NFT system, where gravity would take over; allowing nutrient-rich water to run past the roots of the crops providing before returning to the fish below, where the process would start again. To avoid any issues relating to flooding, the two tanks - i.e. the fish tank and the ionisation tank - were connected together by a small diameter water pipe at high level. This ensured that any excess water in one of the two tanks could escape into the other without causing a flood. Crops were also planted in the top of the filtration media to maximise the productivity of the facade-farm and to ensure all the nutrients were put to good use. For the purposes of the prototype, grow lamps were fitted at the very top of the facade to ensure the crops received sufficient levels of light capture. This was due to the placement of the prototype within the exhibition space, which was placed too far away from natural light for crop growth to occur naturally. Due to structural limitations of the beam and block floor, the heavy facade system had to be supported by a scaffold frame on the floor below, which was out of sight of the public but helped spread the load onto the beams supporting the first floor.



Figure 5.53 - Working facade-farm prototype as seen from the front



Figure 5.54 - Working facade-farm prototype as seen from the rear



Figure 5.55 - Working facade-farm prototype with grow lamps switched on

5.5.3 - Climatic analysis of the facade-farm

The three main contexts envisaged when initially conceptualising the facade was an office building, a supermarket and a hospital. This is primarily due to the typically high cooling loads associated with an office environment as a result of high occupancy and large number of electrical equipment, the natural relationship between food production and food sale in supermarkets, and the benefits living things can provide relating to the health and wellbeing of human beings, which could be particularly useful in hospitals where patients with views of trees and greenery from their windows heal faster with a reduced dependency for medication (Cox, et al., 2017). Within these contexts, it was hoped that the facade-farm would primarily reduce building energy use, in the context of the office, maximise food production, in the context of the supermarket, and improve wellbeing, in the context of the hospital. Beyond improving building performance, increasing domestic food production and improving human well-being, it was also hoped that the facade-farm would also take on the role as an air filtration unit; whereby polluted air would enter the facade and be 'cleaned' before the entering the building; removing dust particles and soot, for example, due to the presence of plants and the humid environment contained within the cavity of the double-skinned facade. The initial testing of the facade-farm, for the first stage of the green genius competition, focused on the ability of such a facade to capture enough light to support crop growth and to ascertain to what effect such a facade would reduce building energy use. This was achieved through the use of building energy modelling software, which would utilise a three-dimensional model to test and determine these two values.



Figure 5.56 - Three-dimensional model and virtual test rig of supermarket facade-farm

At first, the desktop study focussed on determining the thermal impact of a simple double-skinned facade - i.e. a single glazed exterior skin and double glazed internal skin - on adjacent spaces without the presence of any crops. This data would be generated through the extraction of a single bay from a simplified digital model - seen in figure 5.56 - of the facade-farm prototype which would then be tested in three-dimensional space. A horizontal plane was utilised to determine the light capture of the proposed growing plane. The energy simulations were conducted using Autodesk Ecotect; a simple environmental analysis tool that can provide information of such metrics as light and heat capture. All simulations were run between the hours of 8 am, and 4 pm on an overcast day to determine the worst case scenario for the facade-farm. The specification of the exterior and interior glazed panels used in the simulation can be seen in table 5.1.

Table 5.1 - Data parameters for the glazed elements of the facade used in the simulation

	Single glazing (exterior)	Double glazing (interior)
U value (W/m ² K)	5.6	1.4
Solar heat gain refractance	0.88	0.41
Visible transmittance	0.9	0.67

The findings of this initial study, seen in figure 5.57, revealed that a double-skinned facade could reduce the winter heating loads of adjacent spaces by forty percent in winter and reduce the summer cooling loads by seventy percent. The results of this simulation also identified that the demand for heating and cooling, in kilowatts, of the predetermined adjacent space, remained roughly the same throughout the year. Therefore, the energy demand of a building would be much easier to predict, and as such, any power generation - from integrated photovoltaic panels or evacuated tubes - combined as part of the design would become easier to determine and size.

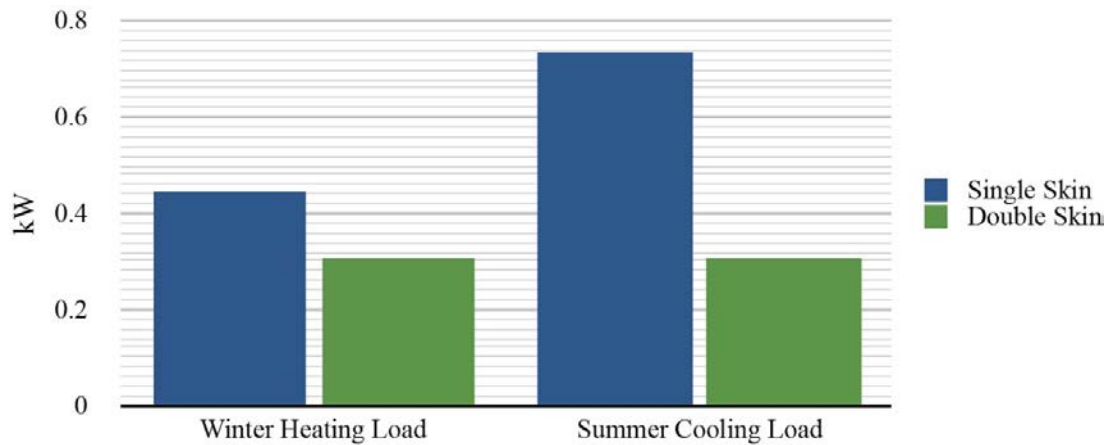


Figure 5.57 - A comparison of single-skin and double-skinned facades relating to the energy demands of adjacent spaces for heating and cooling in winter and summer

After the potential benefits of a simple double-skinned facade were confirmed via the simulation software, the ability of such a facade to support crop growth needed to be understood. Some plant species require a minimum of $1 \text{ MJ/m}^2/\text{day}$ of light energy to survive, which is approximately 7,900 lux or 0.28 kWh/m^2 . This is known as the Photosynthetic Active Radiation value or PAR. To obtain maximum growth rates, however, some plants require $3 \text{ MJ/m}^2/\text{day}$, which is closer to 23,700 lux or 0.83 kWh/m^2 (Badgery-Parker, 1999). The simulation conducted to determine whether double-skinned facades could support crop growth was initially conducted on a facade facing due south on an overcast day, on the basis that if the facade was unable to grow crops in this situation, the design would need to be reconsidered.

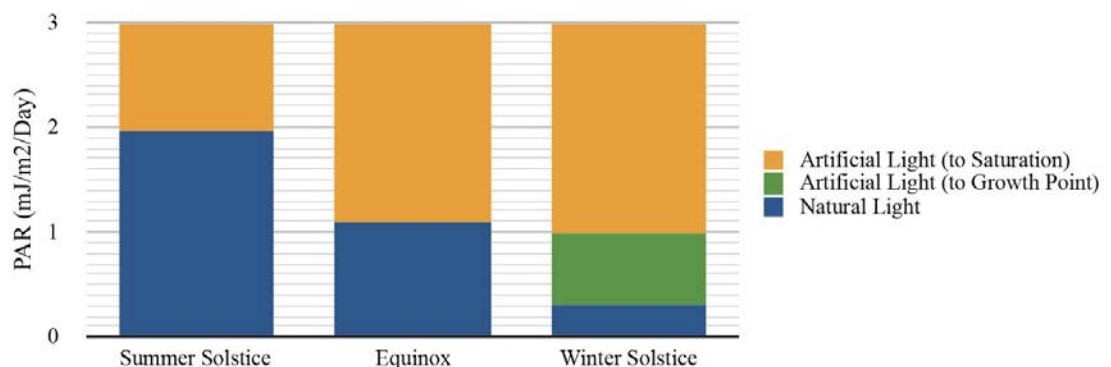


Figure 5.58 - Energy received by a south facing facade-farm with a requirement of $1 \text{ MJ/m}^2/\text{day}$ to initialise plant growth

The results in figure 5.58 confirmed that during the summer solstice and the two equinoxes, a south-facing facade-farm was able to capture the minimum light levels required for crop growth. It is only during the winter months that artificial lighting would be needed to subsidise natural daylight to reach the minimum light levels required. The data generated by the simulation also identified that artificial lighting would be required throughout the year if maximum growth rates were required. Further analysis was then undertaken to research the importance of orientation on the development of the facade-farm and its ability to support life. It is known that the south facade of any building receives the largest proportion of direct sunlight throughout the day, but it was discovered that it would also be possible to grow crops in facade-farms facing any direction during the UK summer time, with all orientations meeting the minimum requirements for light capture. In winter, however, none of the orientations would reach the minimum energy requirements without further input from artificial lighting.

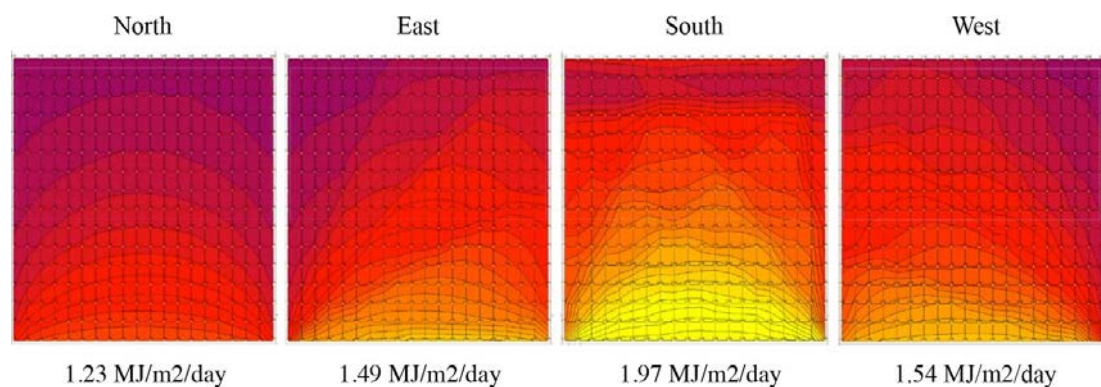


Figure 5.59 - Light energy received on the growing plane within the facade farm facing different orientations during the summer solstice in the UK

Table 5.2 - Average daily light capture throughout the year for facade-farms with different orientations

	(MJ/m ² /day)			
Orientation	Summer	Equinoxes	Winter	Annual
North	1.23	0.77	0.30	0.77
East	1.49	0.86	0.31	0.88
South	1.97	1.09	0.36	1.13
West	1.54	1.69	0.30	0.89

This initial desktop study proved that double-skinned facades are capable of supporting the growth of crops and hints at the potential future of facades as farms. It is believed that the introduction of plants to this study in the future as well as the introduction of variable inclined growing channels would further help regulate the internal conditions of adjacent spaces. It is expected that the use of water within a facade-farm would allow opportunities to help equalise the energy capture of different orientations of facades that constitute a single building throughout the year; as a result of diverting warmer water to cooler areas of the building in summer and winter - to equalise heating and cooling loads - thereby, distributing energy capture falling upon building surfaces more equally and putting it to good use. The implementation of a hardware/software approach to the development of the facade-farm will ultimately enable the system to exist in any climate or bioregion, due to interchangeable and upgradable hardware and a flexible ecological environment, that will be capable of supporting different combinations of living things. Resulting in a flexible facade system that can hopefully improve food access and food security across the world, whilst reducing building energy demand and creating new opportunities for economic growth.

5.5.4 - Inputs and outputs

The facade-farm prototype was capable of delivering 15 crops per metre squared, in elevation at any one time, inclusive of the space required by the fish tanks and

filtration units. If the facade-farm were to replace a theoretical south facing supermarket facade to the magnitude of 50 metres long, by 9 metres high, the facade would be capable of producing 6,750 crops at any one time, which would equate to a productivity of 27,000 crops per annum and a sale value of £54,000; based on four harvests per year and a sale value of £2 per crop, as determined previously in this chapter. For the purposes of the prototype, the facade was only stocked with five fish, which only required a pinch of food each day. As a result, the food intake of the fish was not measured during this first-phase of testing. However, it can be assumed - based on the large system consisting of over five hundred fish and costing £1 to feed per day - that the fish within the facade-farm cost £0.01 to feed per day. The two pumps collectively required 0.075kWh to run continuously, which would cost £0.01 per day; based on a unit price of £0.15 per kWh. The initial water fill of the facade was 700L, which would have cost £1.25; based on a unit cost of £1.78 per 1,000 litres. Although the facade-farm would need to be redesigned to clad a supermarket successfully, a facade of this design and of the size previously stated - i.e. 50 metres long by 9 metres high - would require 42,000 litres of water, which would cost approximately £75 at startup and £42 throughout the year to top up the system based upon 2,000 litres per month, and 648 kWh per annum to run the pumps, which would cost approximately £97.20. It is estimated that the addition of the aquaponic equipment within the cavity of a double-skinned facade would cost approximately £300 per square metre, although it is anticipated that the productivity of the facade could offset this cost with the first three years, with the total cost of the double-skin facade being offset within another seven and half years after that.

5.5.5 - Knowledge acquired and future research

The delivery of a working facade-farm prototype, plus the data gained from simulation studies, identifies the capability of double-skinned facades to simultaneously grow food and reduce building energy demand in the future; both of which increase economic return. The crops within the facade-farm - including purple basil, rocket lettuce and strawberries - thrived in the conditions created within the cavity of the double-skinned facade; proving that urban food systems can adapt and scale in order to make the most of opportunities as they arise as well as maximise the potential and productivity of cities as they stand today. The development of the facade-farm was only possible due to the additional funding received as part of the

Green Genius competition, which was a combined research bid between QUB, BDP and Glassolutions. The producement for the facade-farm prototype can be seen below.

Facade-Farm procurement

1. Call for Green Genius competition
2. Concept design of facade-farm
3. Appointment of BDP and Glassolutions to design team
4. Funding bid submitted to Green Genius competition
5. Bid accepted and funding received
6. Detail design and construction of working facade-farm prototype
7. Climatic simulation of facade-farm

It was found, through simulation studies, that a double-skinned facade can reduce the energy demand of adjacent spaces by approximately forty percent in winter and by seventy percent in the summer. The simulation study also discovered that through the integration of double-skinned facades, the energy demand of adjacent spaces remains the same regardless of the time of year; allowing accurate predictions to be made relating to daily, monthly and yearly building energy use. Most importantly, the simulation study discovered that facade-farms would be capable of capturing enough light to support the growth of crops. However, south facing facades would only be able to produce crops without the need for artificial light for three-quarters of the year, whilst simultaneous growth of crops of all orientations of building facades could only be achieved during the summer months, without the need for artificial light.

The creation of a working facade-farm prototype allowed the productivity of vertical technical food systems to be more accurately calculated, which was found to be 15 crops per metre squared in elevation at any one time - i.e. 112 crops across a total area of 7.5 metres in elevation - including for the space required for the fish tanks and filtration units. When combined with the data collected from the elevated aquaponic systems - i.e. that vertical systems can produce approximately 26.66 crops per metre squared at any one time - more detailed calculations can be made relating to the productivity of whole cities when considering the integration of rooftop

and facade-based technical food systems. As previously, mentioned, it is anticipated that some of the challenges experienced when integrating the elevated aquaponic system, such as the risk of water ingress and the increased humidity of internal spaces, could be avoided if urban food systems were to be considered and integrated as part of the building envelope. Although the development of the facade-farm is only in the initial stages of development, it provides a realistic avenue for further inquiry relating to vertical urban food systems that will hopefully enable a more holistic approach to building integrated technical food systems in the future.

In the future, it is hoped that the research for the facade-farm can be taken further with regards to testing the effects different plant foliages will have upon the shading of and cooling of adjacent spaces, the construction of a kinetic prototype that incorporates the use of the conveyor belt growing system, to compare the differences in performance and productivity of the static and kinetic facade-farm systems, and to understand, with improved accuracy, the impact facade-farms will have on food production and reduction in building energy demand as a whole.

5.6 - Summary of urban agricultural experiments

The opportunity to design and construct the elevated aquaponic system as well as the facade-farm prototype has allowed conclusions to be made relating to how easy or difficult it is to integrate technical food systems into existing buildings. Simply put, it is not as easy as some might first think or believe. The design and integration of technical food systems within existing buildings will always be constrained by the structural capacity of existing buildings. This is because, in many cases, buildings are not designed or constructed with the idea of food production in mind. Irwell House, for example, was not able to support the heavy weight of the fish tanks, which weighed over 500 kilograms per square metre, due to the construction of the roof and intermediate floors which could only hold 150 and 350 kilograms per square metre respectfully. Therefore, careful consideration was required, along with a close working relationship with structural engineers, to ensure the structural integrity of the building throughout the design and construction of the system. It can, therefore, be concluded that in most cases the structural capacity and integrity of the building's

structure will be the primary constraint facing the implementation of building integrated technical food systems, at least in the near future.

During construction of the elevated aquaponic system, it was also discovered that such systems may pose a risk to human health due to the possible development of *Legionella* bacteria. Although this was considered a low risk, design changes were made to the elevated aquaponic system to reduce this risk further. This was achieved by reducing, or containing, splashing and the creation of water aerosol, promoting the movement of water throughout the system, adding high-powered ultraviolet filters after the fish tanks, the filtration unit and the window system to restrict the spread of *Legionella* if it was present, as well as implementing regular water test as part of the maintenance manual, to name a few.

One of the more influential discoveries made throughout this process was the risks building integrated technical food systems can pose to existing buildings, such as water ingress that can result in structural damage and the possible degradation of internal spaces as a result of humid environments. The tanking of internal floors and the improved ventilation of internal spaces could help mitigate these risks to a certain extent. However, it is believed that the best way to resolve these issues is to not place technical food systems within buildings in the first place. It is, therefore, recommended that building integrated technical food systems should only be considered on the rooftops, or facades, of existing buildings, at least in the near future, due to the inherent water-resistant properties of these building elements. Although this would require the use of transfer beams and transfer floors at roof level, it would ultimately reduce the risk of water ingress, restrict the creation of humid environments, remove the need for artificial lighting and would not result in a net reduction in lettable or livable area within buildings.

The construction of both the elevated aquaponic system and the facade-farm has provided critical information relating to the primary technical challenges that face the integration of technical food systems within existing buildings that form today's cities. Additionally, they have also provided information relating to the productivity of horizontal and vertical systems. In the next chapter, the metrics for both horizontal and vertical systems - determined by the elevated aquaponic systems and the facade farm respectively - will be applied to simulated light capture data in order to

determine the productive capacity of building integrated technical food systems within the collective inner urban area of the United Kingdom.

6.0

FUTURE

INTEGRATION

6.0 // FUTURE INTEGRATION //

In chapter 5.0, the technical challenges associated with the integration of urban food systems within existing buildings were identified and discussed as a result of the design and construction of an elevated aquaponic system as well as the development of a facade-farm prototype. Now the thesis aims to utilise the metrics collected from the elevated aquaponic system and the facade-farm to calculate the productive capacity of inner city areas, and to determine the impact naturally-lit technical food systems may have on both the food security of the UK and the mitigation of ecological damage. In addition to this, the chapter also identifies the potential additional benefits of building integrated technical food systems and discusses how these benefits may affect the psychological, physiological and financial wellbeing of urban populations.

6.1 - Future placement of technological food systems

The primary technical difficulty faced during the delivery of the elevated aquaponic system was the structural capacity of the building. As a result, careful consideration was required when positioning the fish tanks, filtration unit and rooftop polytunnel, and structural alterations were required to ensure the safety of those working around the system and those visiting it during the festival. Due to the use of multiple sumps, a control system was also required to reduce the risk of sumps overflowing, which could result in structural damage. The secondary issues relating to the design of the elevated aquaponic system was the creation of humid environments and the possible growth of Legionella bacteria. The construction of the elevated aquaponic system brought up serious questions as to whether such systems should be contained within buildings due to the risks posed by the presence of water. Hence, the decision was made to focus on exterior systems - i.e. those that exist on roofs or facades of existing buildings - for the remainder of the research, to mitigate the risks posed by water ingress and humidity, and to make use of natural light, where possible. In order to answer research question two and components of research question three, the productive capacity of at least one city needed to be known. To generate this information the productivity metrics taken from the elevated aquaponic

system and the facade-farm had to be mapped onto an existing city. However, this would not be a simple process because such an analysis relies on accurate data relating to the surface area of a city and the light capture of different urban surfaces. This analysis is required because every building facade and rooftop within a given city receives a different level of light capture each day and throughout the year, and in some instances, may not be able to support the growth of crops. For example, the roof of a tower with no other buildings around it will capture a significant amount of light through the day, whereas a north-facing facade along a tight street would have poor access to light. To be able to calculate both the surface area of the city and the light capture of individual built surfaces, simulation research was considered to be the best method of analysis in order to determine the proportion of the city's surface area that is capable of supporting crop growth. Although studies have been conducted previously relating to the viability of urban surfaces to support crop growth (Songa, et al., 2018) - focussing on the reduction in PAR (Photosynthetically Active Radiation) as a result of facade orientation and height - the conclusions made simply state that orientation and height of facades will affect crop growth; i.e. no mention is made of how such findings would impact the food production of a building, city or nation. Other studies have utilised light analysis to calculate the quantities of food that could grown if all grassy areas within and around a major city were to be converted in to agricultural plots (Richardson, et al., 2016). However, large assumptions are made relating to the productivity of food per hectare and the study area of 21,700 hectares is significantly greater than any of the study areas presented in this thesis, which is why the analysis provided in this chapter is essential when striving to understand and address the impacts of light capture on the productivity of building integrated technical food systems.

6.1.1 - The use of simulation research

The benefits of simulation research were identified in chapter three but to reiterate the points made; simulation research allows virtual experimentation to occur without the ethical, practical or financial barriers associated with the same experiment in a real-world context. Within the boundaries of the thesis, and specifically, when discussing research question two, there are multiple methods that could be utilised to calculate the surface area of a city and the light capture of each building surface. For example; the height and building plot of individual buildings could be measured

with the use of powerful laser equipment, which would allow the surface area of each building to be known. When this process is completed for every building within a given study area, the surface area of the city can be calculated very accurately. This process, however, would be time-consuming and would cost a significant amount of money. In addition to this, merely calculating the surface area of the city would not allow any deductions to be made relating to the proportion of the surface area that was capable of supporting crop growth. Additionally, the light capture of a building could be calculated through the use of sensors upon each facade, which would give very accurate measurements. However, the time required to capture this data for an entire city, and the cost associated with this process, would make it an impractical method of analysis. To avoid both the time and cost constraints associated with real-world data capture, a three-dimensional virtual model of a given city can be created and utilised to generate the data required. By combining the surface area of the city that is capable of supporting crop growth with the metrics from the elevated aquaponic system and the facade-farm, the productivity capacity of the city - i.e. the maximum number of crops it could theoretically produce at any one time - can be calculated.

Once the productive capacity of at least one UK city is known, it would then be necessary to calculate the productive capacity of the remaining sixty-five UK cities in order to derive conclusions relating to the impact of naturally-lit building integrated technical food systems on UK food security and the mitigation of ecological damage. One method that could be utilised to gather the data for the remaining sixty-five cities would be to create a virtual three-dimensional model for each individual city and conduct the same light capture analysis as the first city. However, this process would again take an extraordinary length of time to complete, so another method of analysis would be required. In order to improve the efficiency of data capture related to research question two, simple observations can be made regarding the relationship between the area upon which the first city sits and the productive capacity of that city. The relationship between these two entities can then be used to formulate an equation that can be applied to all the remaining cities based upon the inner urban area of each city alone. Although this method of inquiry includes some generalised assumptions, which will ultimately lead to an unknown margin of error, it nonetheless will provide a base point from which the impacts of urban agriculture on UK food production and mitigation of ecological damage can be discussed. Future

studies can then use this initial analysis as a springboard to generate new research with improved accuracy.

In order to generate the initial information required to determine the relationship between geographical area and productive capacity, a three-dimensional virtual model of the chosen city was built, which utilised accurate building blocks obtained from Digimap, which were then extruded to the relevant building height provided by LiDAR data - Light Light Detection and Ranging - from Land Map. Due to the unknown technical challenges associated with technical food systems that exist upon pitched roofs, and the lack of productivity data for such systems within this thesis, pitched roofs were omitted from the study. As a result, each building volume was modelled with a flat roof for simplicity because the impact of pitched roofs on annual overshadowing was considered negligible. It should be noted that this study only focuses on the productivity of naturally-lit building integrated technical food systems within inner urban areas in order to mitigate the risks posed by internal water-based systems, maximise the productivity of such systems where building density and building height is greatest, and avoid the limitations posed by ground-level systems such as increased competition for land and poor scalability.

6.2 - Light capture analysis

Unlike the design of a technical food system, which can be improved to minimise the complications associated with its integration, cities exist as they are today and are not capable, within the realms of possibility, of being changed to suit the objectives associated with urban food production. Therefore, if cities suffer from too much overshadowing due to high-density building plots, for example, then the future of urban agriculture may be questionable. However, if through simulation research it is discovered that cities are capable of supporting crop growth on most, or all, of their surface area, then urban agriculture could become a prosperous industry. To generate the data required to calculate the productive capacity of a single city a detailed method of investigation was required. For the purposes of this thesis, it was deemed necessary to explicitly describe each step of the light capture analysis so that the method could be understood, appropriated and modified by others in due course. This explicit description of the process also provides an opportunity for

others to judge the appropriateness of the method with regards to the research objectives of the study.

It should be noted that although the availability of light is one factor affecting the implementation of building integrated technical food systems, in addition to the technical challenges identified in the previous chapter, the thesis understands that other factors such as finance, access to the right skills and a willingness of building owners to partake in urban agriculture, are all contributing factors that will determine the future of agriculture within cities. Therefore, this method of analysis is intended to be utilised at a municipal scale to enable discussions to occur between local authorities and community groups and to identify which areas of a city are best suited to agricultural activities. For this initial analysis, the city centre of Manchester, England was used to help derive and test the method of analysis. The primary reason for this choice was the proximity of the elevated aquaponic system to the city centre of Manchester, which occupies an area of approximately 360 hectares. The following analysis strives to calculate the percentage of the surface area of the city of Manchester that is capable of supporting crop growth and as a result, determine the productive capacity of the city per geographical hectare; i.e. per hectare of land, not per hectare of building area.

6.2.1 - Three-dimensional modelling

To make it possible to determine upon which surfaces of the city crops could be grown, the overshadowing of each horizontal and vertical surface must first be visualised and understood. This would be achieved by creating an accurate three-dimensional representation of the city of Manchester within virtual space onto which virtual light rays can be cast. The inner urban area of the city of Manchester was defined by the major vehicular routes that encircle the city and provide natural breaks; beyond which, density and building heights drastically decrease. These transport boundaries consist of Great Ancoats Street to the east, Trinity Way to the north and west, and Mancunian Way to the south, as shown in figure 6.1.



Figure 6.1 - Inner urban area of Manchester

To create the virtual model of Manchester more than 2800 building plots were created in three-dimensional space, with each plot containing information on building form and building height. Both of these characteristics would be crucial when determining overshadowing, and therefore the reduction in light capture of adjacent building surfaces. As mentioned in chapter three, simulations can be as simple or as complex as required dependent upon the needs of the study. For example, every window reveal and door opening could be modelled in three-dimensional space. However, the effect on the overall light capture analysis would be negligible. Therefore, all building plots were modelled as simply blocks with flat roofs, due to points raised previously relating to pitched roofs. Although the pitched roofs of the city were not considered as a viable location for food production at this point in time, it is not to say that they could not form an integral part of future urban food production. For example, these areas would be perfect locations for the generation of electricity or hot water; both of which are crucial to the production of crops within technical food systems. The data used to create the virtual model of Manchester was taken from Digimap (digimap.edina.ac.uk) and Land Map (www.landmap.ac.uk), which identified the planform and height of each building plot respectfully. The data from Landmap is referenced as originating from Cities Revealed which is now part of the Geoinformation Group.



Figure 6.2 - Completed three-dimensional model of the city of Manchester

6.2.2 - Solar positioning and visual presentation

Once the virtual model of the city of Manchester had been created by the author of this thesis, it was then capable of accepting computer-generated light rays to produce accurate shadow maps. To collect the initial shadow data, a physical sun object was added to the scene, which makes use of metrics such as latitude, longitude, time of the day and month of the year to determine the sun's position. The latitude and longitude used for Manchester was $53^{\circ}29'N$ and $02^{\circ}12'W$.

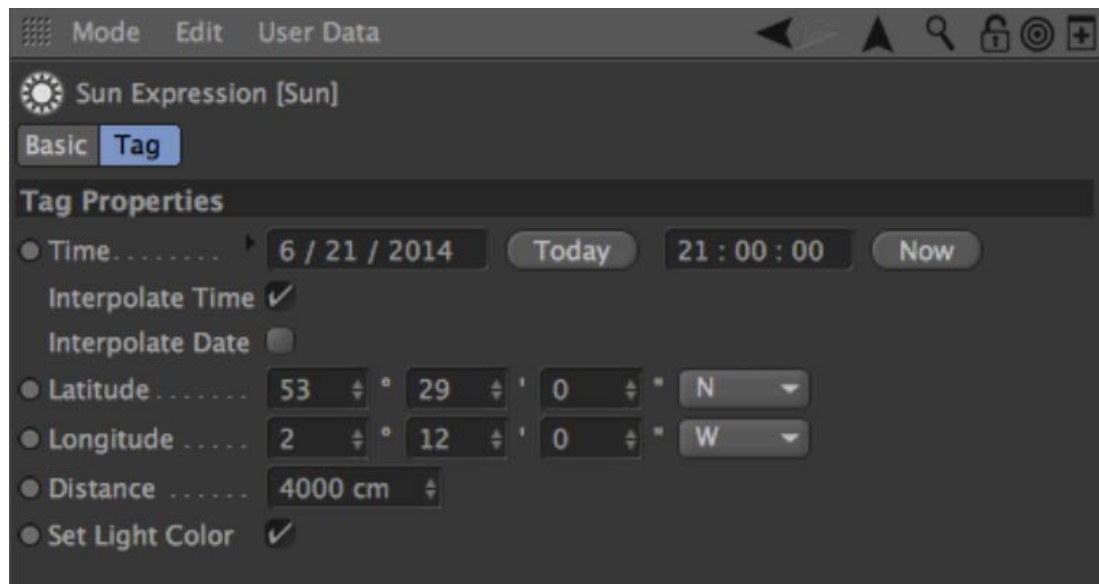


Figure 6.3 - Sun object data entry

The main difficulty associated with utilising a three-dimensional model in this context is how to best represent the data as a two-dimensional image. To resolve this, the horizontal and vertical datasets were separated. The light capture of the horizontal surfaces - i.e. roof spaces - would be captured directly from above as one would view the plan of a building. In contrast, the vertical data - i.e. building facades - is more difficult to represent as a single image. Therefore, two views with different vantage points would be utilised to fully understand the light capture of the vertical surfaces of the city. These two views were taken from the south-east and the south-west, at an elevation of 60 degrees, and in parallel projection. No data is represented for the north facing surfaces of the facade study because it can be assumed that these surfaces would be overshadowed for the majority of the year and would only receive diffused radiation. The software used to model the city and capture the shadow information was Maxon Cinema 4D. However, many three-dimensional modelling programmes offer very similar options and controls.



Figure 6.4 - Rooftop shadow map / June 21st at 14:00

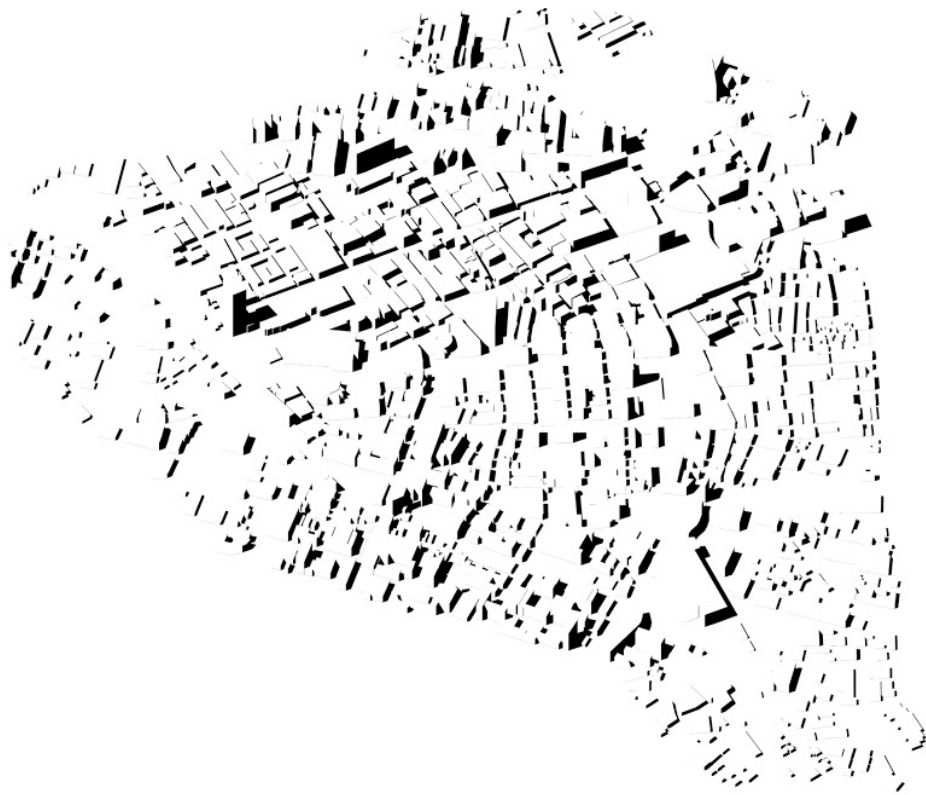


Figure 6.5 - South-east facade shadow map / June 21st at 14:00

6.2.3 - Creation of shadow maps

To create the shadow maps that would inform the light capture analysis, individual images were taken from the three vantage points described previously at half hourly intervals, from sunrise to sunset, to represent a 'typical day' within each month. The 21st day of each month was used to represent a 'typical day' within the study, due to the winter and summer solstices occurring on the 21st of December and 21st of June respectively. Initially, renders were taken every hour to speed up the process, but the deviation between each shadow was too severe, which would lead towards errors later in the process. Therefore, renders were taken every half-hour to counteract this. The azimuth data as well as elevational data for the sun on equivalent months (i.e. January and November, February and October, etc.) was almost identical and showed minimal deviations from east to west. Therefore, for the purposes of this analysis, these 'equivalent months' share the same shadow map due to the negligible differences in the metrics associated with the azimuth and elevation of the sun. The light capture for the winter and summer solstices have their own shadow maps and do not adjoin with any other months. In total, over 250 images were taken to represent each half-hourly shadow on a single day within each month of the year from the different vantage points identified. In order for the individual shadow maps to be collated into monthly and annual light capture studies, the shadows themselves had to be isolated from the original image, which can be seen in figure 6.6.

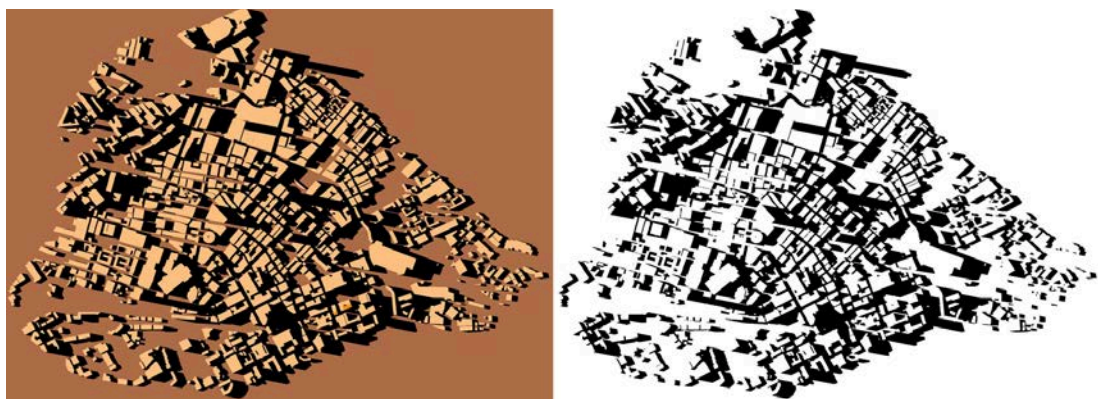


Figure 6.6 - 19:00 May 21st before and after shadow separation

Once the shadows had been separated from the rest of the image, each half-hourly shadow was laid on top of one another in Adobe Photoshop, and an arbitrary opacity was applied to each shadow to create a gradient map; as shown in figure 6.7. Where multiple shadows coincided, darker patches would be seen, and areas mostly out of shadow would be represented as lighter patches. This approach, however, did not accurately represent the impact of a single shadow on the daily solar capture of a surface throughout the day; i.e. an area in shadow at midday would see a significant decrease in its overall daily light capture compared with an area that was only in shadow during sunrise or sunset.



Figure 6.7 - April 21st daily shadow map with ubiquitous shadow opacities

To address this issue the impact of each half-hourly shadow on the total possible daily light capture of a single surface for each given day needed to be calculated. To calculate this information SolarGIS - who supply solar data for photovoltaic projects - were contacted. SolarGIS very kindly allowed access to their information, which included accurate data ($\pm 3\%$) on sun paths and solar radiation for Manchester (see Appendix R). The sun path data would be of most use at this stage as it would allow the area under each sun path to be divided into half-hourly segments in order to determine the percentage contribution of each half-hourly segment to the total

daylight capture of a given day (see figure 6.8). The measurements relating to the sun paths and half-hourly segments were calculated with the aid AutoCAD because it provided a platform in which accurate curves could be drawn, and areas could be quickly calculated.

Taking April 21st as an example of this process; the day consists of twenty-five half-hourly periods where the city of Manchester was receiving light. The sun path was, therefore, divided into twenty-five equal sections laterally - noted in figure 6.8 as 'A' through to 'Y' - and the area of each section was calculated as a percentage of the overall area of the sun curve, which can be seen in table 6.1. When looking closely at the data in table 6.1, it can be seen that the light falling on a surface between 13:00 and 13:29 accounts for 6.2 percent of its total daily light capture, whereas the light falling between 07:00 and 07:29 accounts for only 0.4 percent of its total daily light capture. Therefore, a surface only in shadow between 13:00 and 13:29 would see a reduction in its total daily light capture of 6.2 percent whereas a surface only in shadow between 07:00 and 07:29 would only see a 0.4 percent reduction in its daily solar capture. Hence, shadows towards the middle of a day have a larger impact on daily light capture and should, therefore, be represented as darker, when compared with shadows towards the extremities of the day.

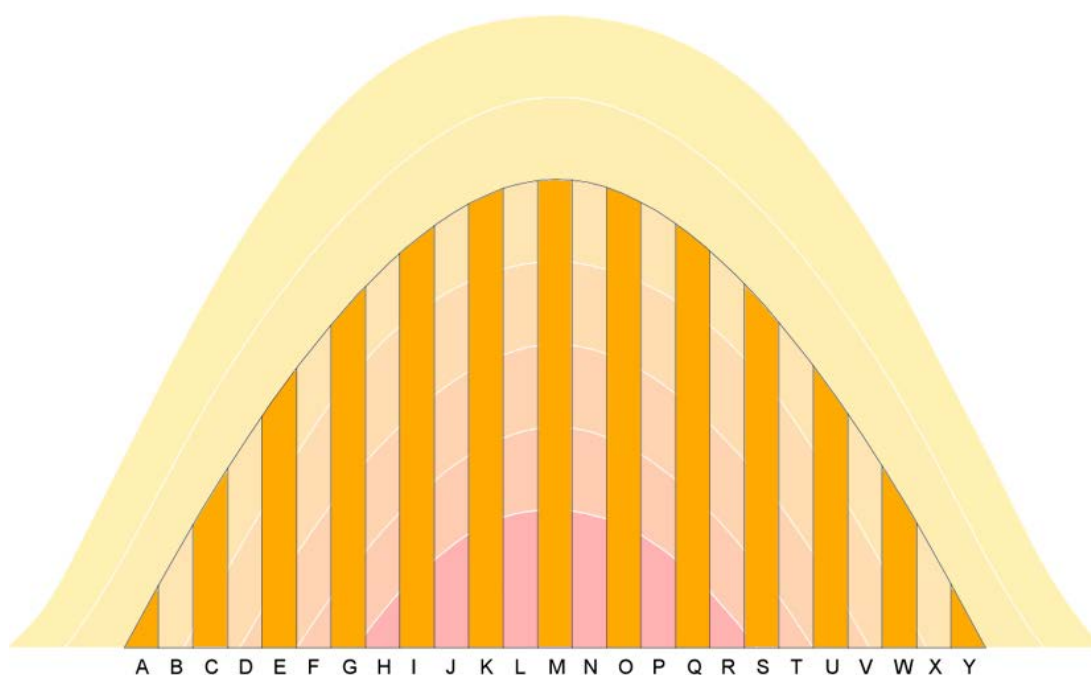


Figure 6.8 - Sun curve of April divided into twenty-five half-hourly segments

Table 6.1 - The proportional impact of each half-hourly shadow on total daylight capture during 21st April

Time	Section	Percentage
7:00	A	0.4
7:30	B	1.2
8:00	C	2.0
8:30	D	2.7
9:00	E	3.4
9:30	F	4.0
10:00	G	4.5
10:30	H	5.0
11:00	I	5.4
11:30	J	5.8
12:00	K	6.0
12:30	L	6.2
13:00	M	6.2
13:30	N	6.2
14:00	O	6.0
14:30	P	5.8
15:00	Q	5.4
15:30	R	5.0
16:00	S	4.5
16:30	T	4.0
17:00	U	3.4
17:30	V	2.7
18:00	W	2.0
18:30	X	1.2
19:00	Y	0.4

Once this proportional impact had been calculated the percentages could then be applied to each shadow layer in Adobe Photoshop to give a more weighted appearance; i.e. the shadow layer for 8:00 on April 21st would have an opacity of 2

percent applied to it and the shadow layer for 15:30 on April 21st would have an opacity of 5% applied to it, as per table 6.1. However, the visual difference between an opacity of 0.4 and 6.2 was almost negligible - as illustrated in figure 6.9 - so the percentages were multiplied by a factor of five to allow a greater dynamic range to be achieved; as illustrated in figure 6.10. This process of increasing the dynamic range of the image visually presented areas that are always in shadow as black, as opposed to light grey, and areas that are never in shadow as white. For the impact and opacity data relating to each month, please refer to Appendix R.



Figure 6.9 - April 21st daily shadow map with weighted shadow layers, as per table 6.1



Figure 6.10 - April 21st daily shadow map with weighted shadow opacities, as per table 6.1, and increased dynamic range by a factor of five

To better represent the difference between the ubiquitous opacity method and the weighted opacity method, a section of the three-dimension virtual model was isolated and the shadow study conducted again using the two different methods. Using this example, it can be seen that the ubiquitous method represents some areas as receiving more radiation than is the case, which is illustrated in figure 6.11. The weighted method represents areas that are always in shadow throughout the day as black, rather than grey, which is simultaneously more accurate and easier to work with and interpret, as illustrated in figure 6.12.

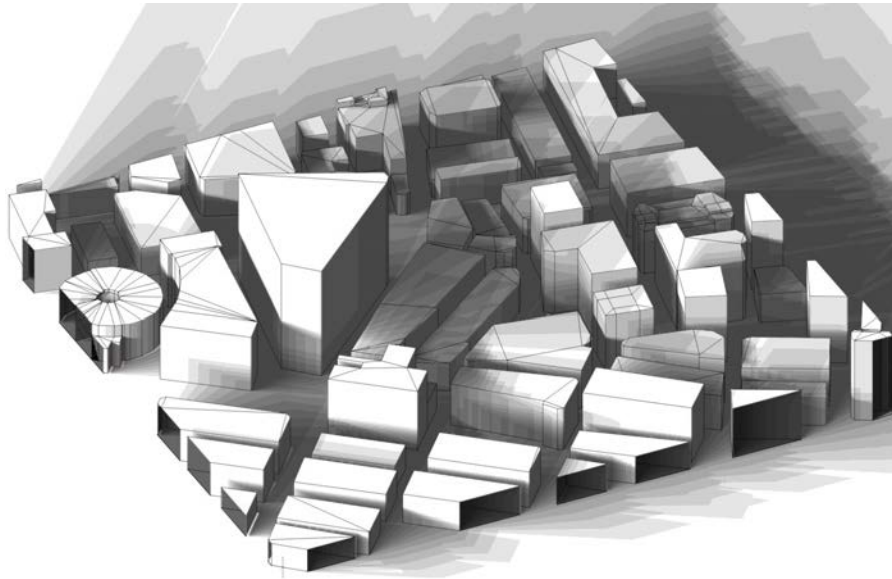


Figure 6.11 - Portion of three-dimensional virtual model with ubiquitous shadow opacities



Figure 6.12 - Portion of three-dimensional virtual model with weighted shadow opacities

The final stage in producing the shadow maps was to combine the shadow information with the accurate irradiation data from SolarGIS, which included both direct irradiation - i.e. direct sunlight - and diffused irradiation - i.e. diffused light from the sky. An area in continual shadow would only ever receive diffused irradiation from the sky, whereas an area in constant sunlight would always be exposed to the total direct irradiation value for that given day. Again, taking the light capture data for April 21st as an example, the total daily direct irradiation is 3.33 kW/m²/day and the

total indirect irradiation is 2.09kW/m²/day (see Appendix R). Therefore, it can be assumed that all areas of the shadow map that are solid black - i.e. always in shadow - would have an energy capture of 2.09kW/m²/day whereas the areas in constant sunlight would achieve an energy capture of 3.33kW/m²/day. The resulting image represents which roofs are susceptible to overshadowing, and how much energy each surface receives throughout the day within each month. Upon completing the shadow maps, it was essential to identify all the pitched roofs and eliminate them from the study - due to the reasons previously stated - as well as the ground level data which would have no impact on rooftop crop production. It should be noted that if Manchester were to be comprised entirely of flat roofs, it would have a total roof area of 136.3 hectares. However, 44.2 percent of the buildings in the city have pitched roofs, leaving the remaining flat roof area to be 76 hectares. To increase the clarity of the map the individual shadows were merged into a stepped gradient, which offers an opportunity to grade the irradiation data by fixed increments. This then enables the use of a key to allow a clearer insight into the data collected. Please refer to Appendix R for the full array of monthly rooftop shadow maps.

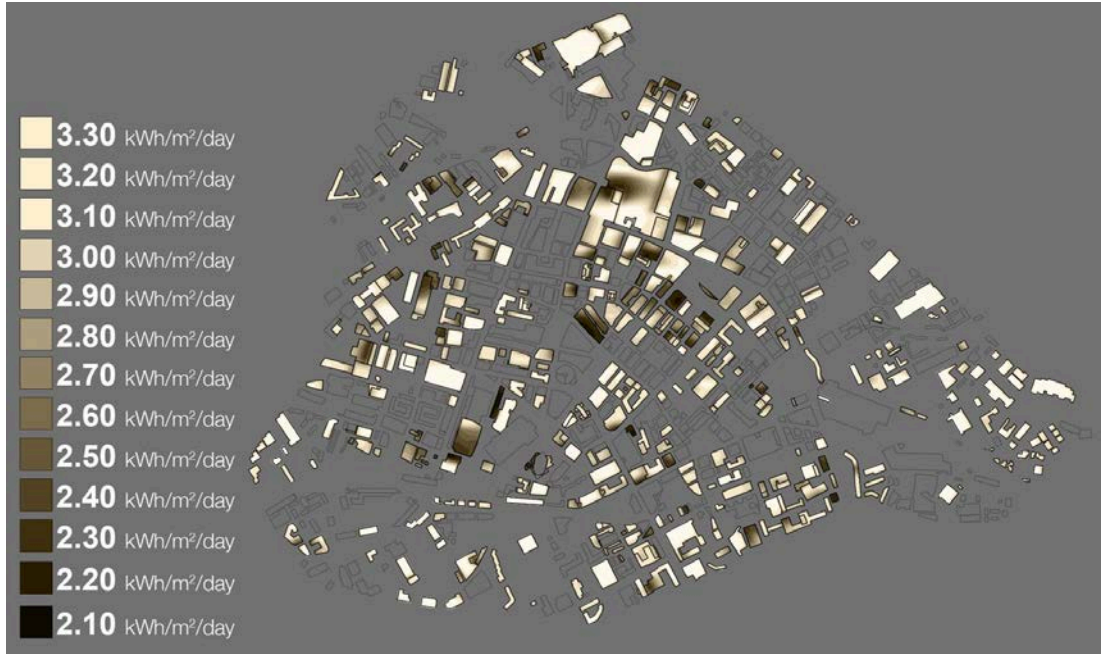


Figure 6.13 - Completed daily shadow map for April 21st

6.2.4 - Facade shadow maps

The facade shadow maps were produced in the same way as the rooftop shadow maps. These were however taken from two vantage points to best represent the data generated by the three-dimensional virtual model in two-dimensional space. The only step that was omitted when producing the facade shadow maps is the last process of creating a stepped gradient map. The facade surfaces are visually much smaller than the roof surfaces and so the stepped gradient did not add any further clarity (see figure 6.14). Initially, the facade analysis began in the same way as the rooftop analysis; i.e. producing shadows maps for January, February, etc., but the differences between each month were far more nuanced than the rooftop shadow data. Hence, the decision was made to include only the winter solstice (December 21st), equinoxes (March 21st and September 21st) and the summer solstice (June 21st) as part of this analysis to create a visual distinction throughout the year. Please refer to Appendix R for all the full array of facade shadow maps. Please refer to Appendix R for the full range of facade shadow maps.

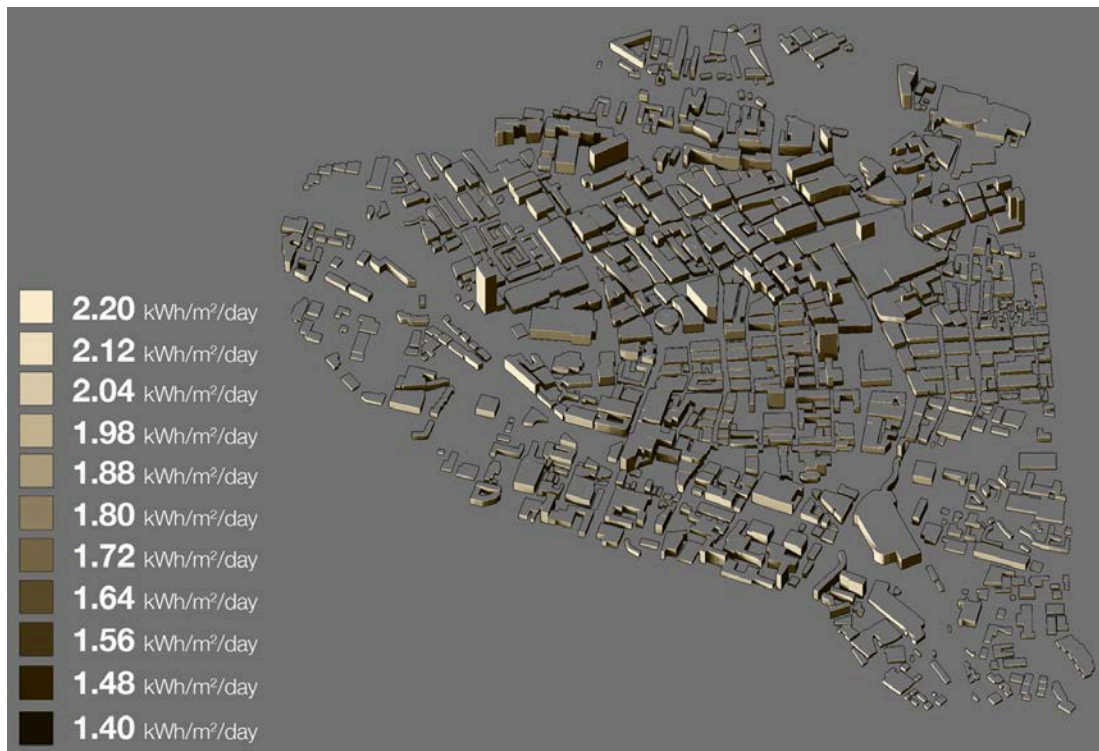


Figure 6.14 - March 21st facade shadow map from the south east

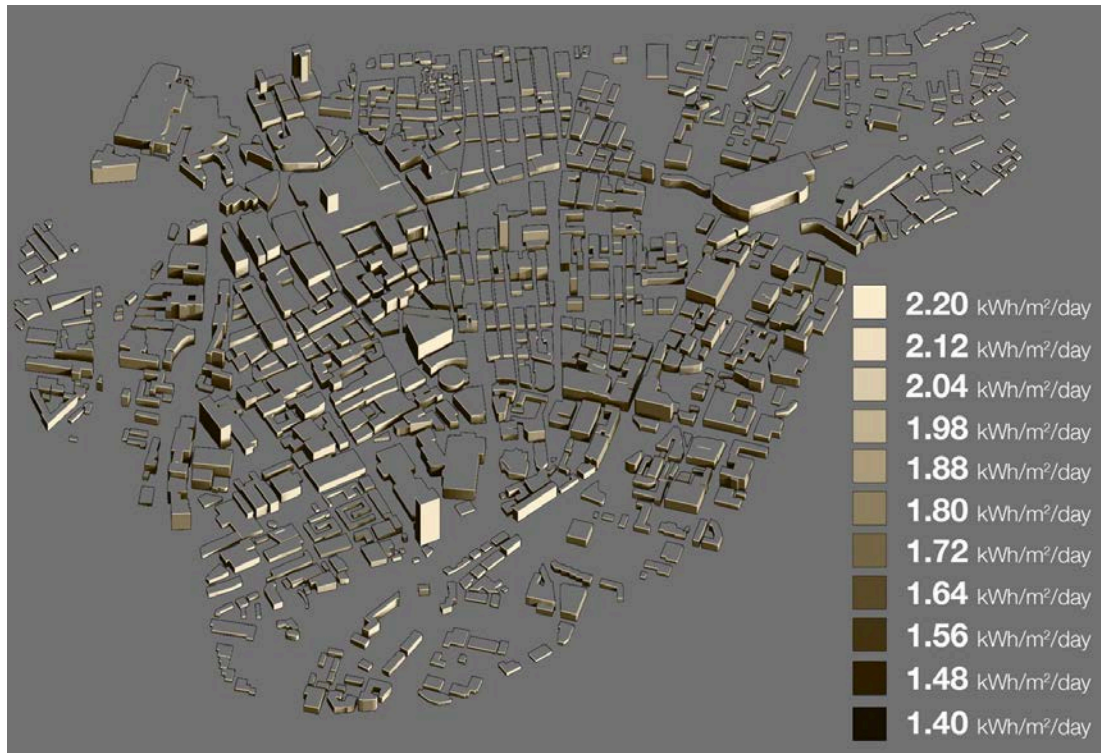


Figure 6.15 - March 21st facade shadow map from the south west

6.2.5 - Average annual light capture

To determine the productive capacity of the horizontal and vertical surfaces of Manchester throughout the year, the light capture data for each month would have to be combined to create an annual representation of light capture. This would be achieved by layering each half-hourly shadow from each month on top of one another in Adobe Photoshop and then recalculating the proportional impact of each shadow on yearly light capture; i.e. the area of each half-hourly segment from each month would be divided by the combined area of all the sun paths to provide a percentage reduction in annual light capture for each shadow layer. As a result of recalculating the impact of each half-hourly shadow it could be seen, for example, that the light capture of a surface in shadow between 10:00 and 10:29 on December 21st would be reduced by 0.1 percent, whereas a surface in shadow between 12:00 and 12:29 on June 21st would see a reduction in light capture of 0.9 percent. Due to the small impact of each shadow on annual light capture, it was again necessary to increase the dynamic range of the shadow layers to create an interpretable image. In this instance, the shadows associated with December 21st and June 21st - i.e. the

solstices - were increase by a factor of ten, whereas the other shadows were increased by a factor of twenty, due to the fact that every shadow layer represented a shadow in two months; i.e. a shadow at 10:00 on May 21st, would also need to represent a shadow at 10:00 on July 21st (please refer to Appendix R for detailed data relating to the impact and opacities of each shadow layer for the annual light capture analysis). When all the shadow layers are laid upon one another, and the yearly impact opacities of each shadow are applied, an annual lighting map emerges, which can be seen in figure 6.16. Again, for the rooftop analysis, a stepped gradient was added to increase the legibility of the information and to provide a distinction between energy bands across the city but this was not applied to the facade analysis due to the reasons previously stated. Finally, the annual results were processed in blue to help differentiate the annual data from the monthly data.

To interpret the information represented by the annual light capture analysis, it was necessary to convert the units of measurement from kWh/m²/day to 'usable days'. This is because each step of the gradient map represented a wide range of energy values. For example, areas shown as white in figure 6.16 could have an energy level anywhere between 0.48 kWh/m²/day and 4.5 kWh/m²/day dependent on the time of year. To determine the usable days of each energy band, the energy needed by a plant for photosynthesis to occur must be included as part of the calculations. As a working average, some plant species require a minimum of 1MJ/m²/day (0.28kWh/m²/day) of light energy to survive 3MJ/m²/day (0.83kWh/m²/day) to achieve maximum growth rates (Badgery-Parker, 1999). To ensure the maximum productivity of building integrated technical food systems, the saturation point of photosynthesis - i.e. 0.83kWh/m²/day - was used as threshold value to help determine the number of 'usable' days' for each energy band; i.e. the maximum number of days a surface receives energy equal to, or above, 0.83kWh/m²/day. Taking the highest energy band as an example, the usable days can be calculated as follows.

0.83 kWh/m²/day = Threshold value

0.48 kWh/m²/day = Winter solstice maximum energy value

4.50 kWh/m²/day = Summer solstice maximum energy value

$$(1 - ((\underline{0.83} - \underline{0.48}) \div \underline{4.50})) \times 365 = 336.6 \sim \underline{337 \text{ days}}$$

The table below presents the usable days for each energy band, utilising the equation seen on the previous page, with figure 6.16 representing the usable days for roof-based technical food systems and figure 6.17 and figure 6.18 representing the usable days for facade-based technical food systems.

Table 6.2 - Usable growing days across Manchester for each gradient energy band

December 21st energy value (kWh/m²/day)	June 21st energy value (kWh/m²/day)	Threshold energy value kWh/m²/day	Percentage of year usable	Days of year usable
0.48	4.5	0.83	92.2	<u>336.6</u>
0.4625	4.275	0.83	91.4	<u>333.6</u>
0.445	4.05	0.83	90.5	<u>330.3</u>
0.4275	3.825	0.83	89.5	<u>326.6</u>
0.41	3.6	0.83	88.3	<u>322.4</u>
0.3925	3.375	0.83	87.0	<u>317.7</u>
0.375	3.15	0.83	85.6	<u>312.3</u>
0.3575	2.925	0.83	83.8	<u>306.0</u>
0.34	2.7	0.83	81.9	<u>298.8</u>

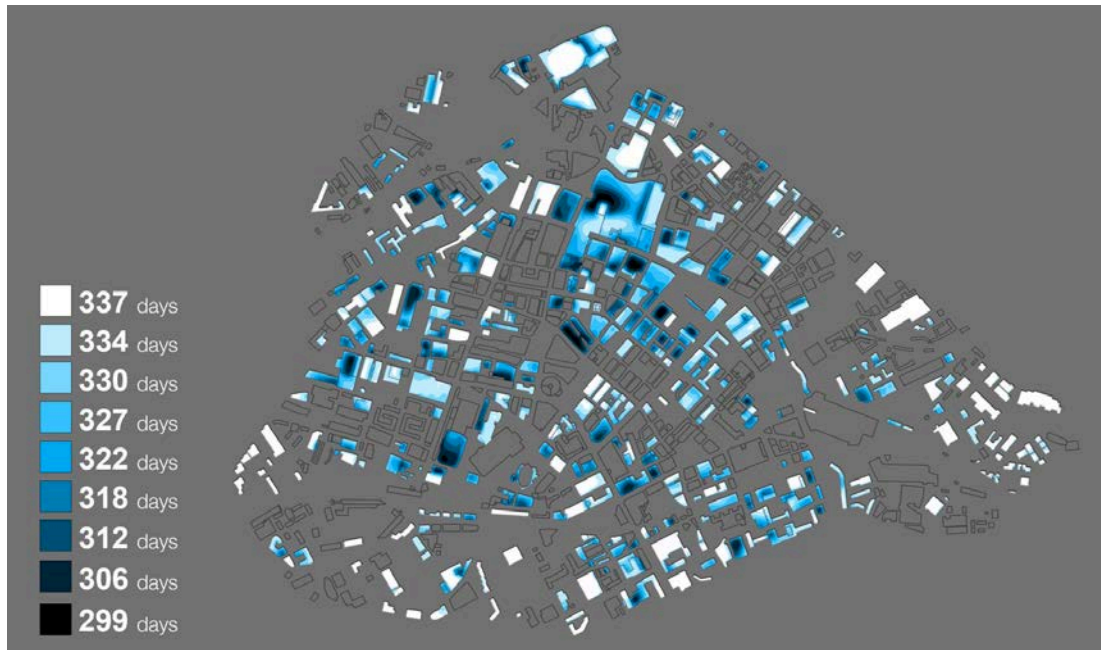


Figure 6.16 - Annual light capture of rooftops in the city of Manchester

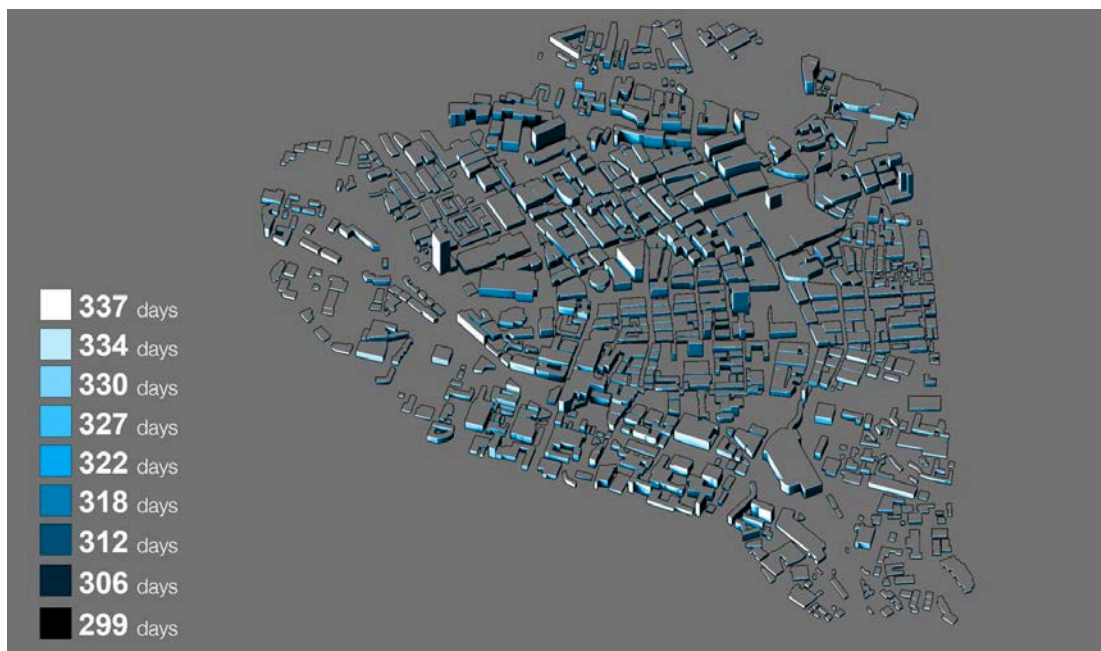


Figure 6.17 - Annual light capture of south and southeast facades in the city of Manchester

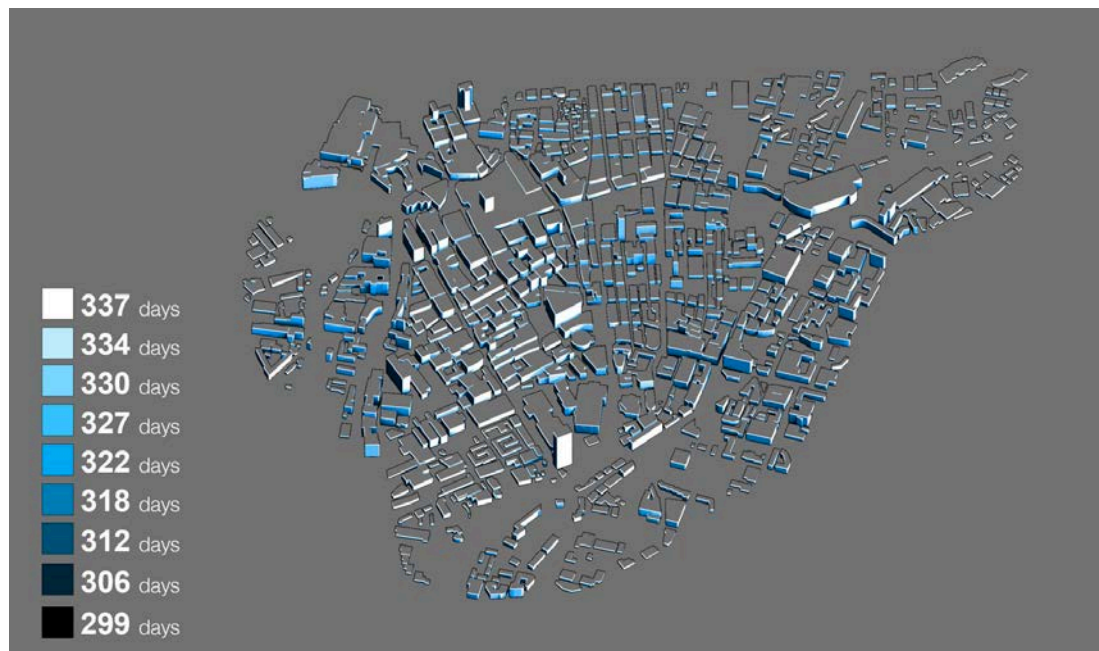


Figure 6.18 - Annual light capture of south and southwest facades in the city of Manchester

6.2.6 - Light capture analysis summary

The elevated aquaponic system drew attention to the primary technical challenges faced when integrating technical food systems within existing buildings. However, in isolation, such a system does not provide any information relating to the productivity of building integrated technical food systems at a city or national scale. When the annual light capture analysis is combined with the productivity metrics of the elevated aquaponic system and the facade-farm, it allows estimations to be made which can further the discussion relating to the productive capacity of UK cities and the UK as a whole. In addition to this, the light capture analysis would also allow informed decisions to be made on a much smaller scale. Taking John Dalton Street in Manchester as an example (see figure 6.19 - 6.21) it can be seen that the lower third of the building in question is subject to heavy overshadowing whilst the top two-thirds remain relatively unimpeded. Therefore, an informed decision could be made to integrate a facade-based technical food system on the upper two-thirds of the building, to maximise productivity and minimise capital expenditure. Light capture analysis can also be combined with other studies to derive additional information, such as a framework or strategy of integration.

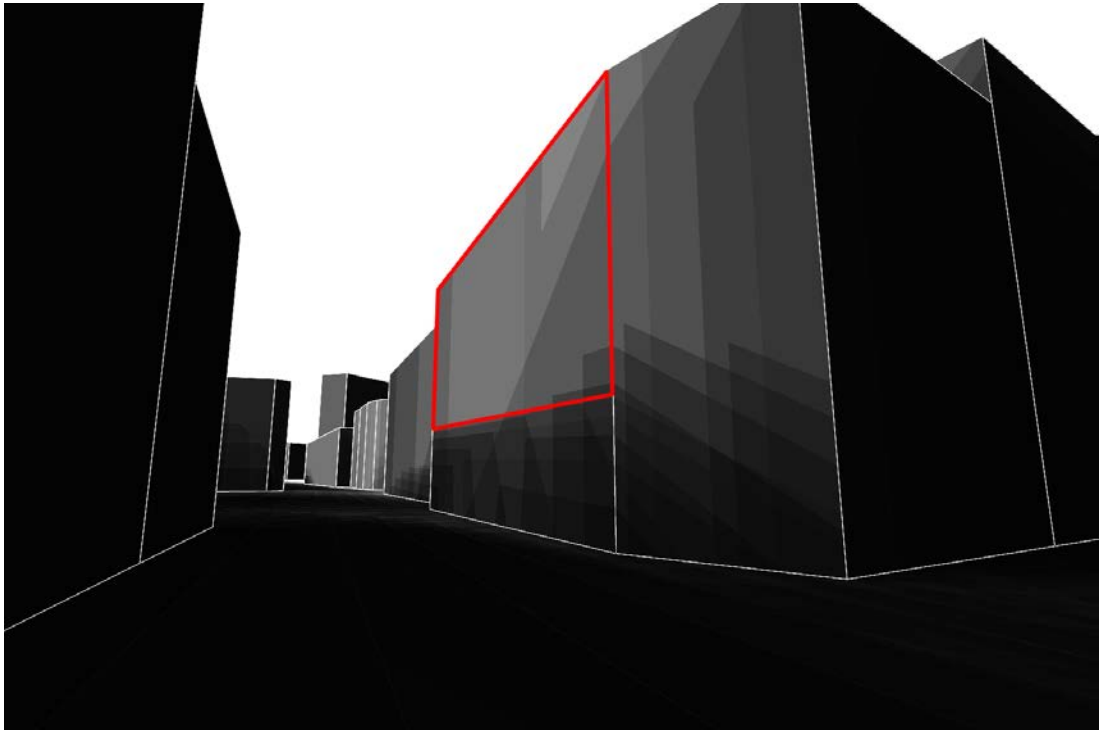


Figure 6.19 - Light capture analysis along John Dalton Street, Manchester facing west

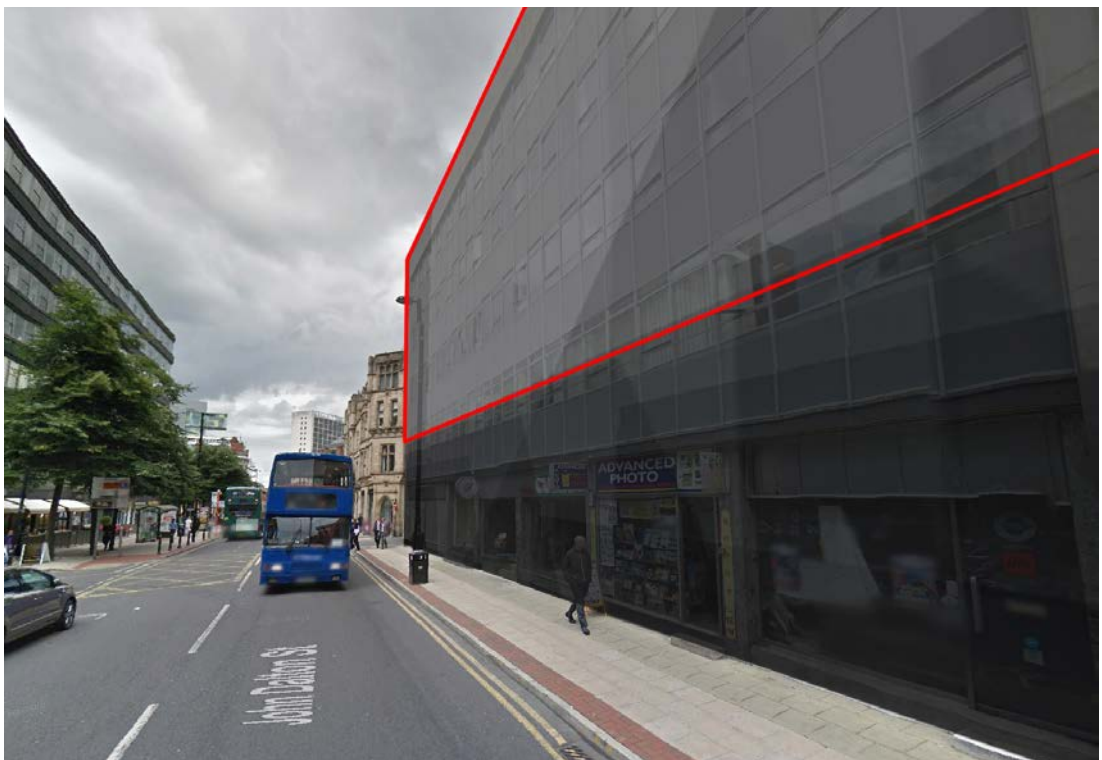


Figure 6.20 - Mapping of the shadow study onto real-life urban surfaces



Figure 6.21 - Placement of facade-farm determined by light capture analysis

6.3 - Addition uses for light capture analysis

In addition to enabling the productive capacity of Manchester to be calculated, which will occur in section 6.4, the light capture analysis also allows some additional avenues of inquiry to take place. As mentioned previously, light capture is only one of the contributing factors that will determine the future of agriculture within cities alongside structural capacity, access to skills, financing, and the willingness of building owners to partake in agricultural activities, to name a few. However, the demand for food is also expected to play a key role in the future implementation of building integrated technical food systems - i.e. the ability to sell the food once it has been harvested - and the development of any future strategies of urban food production, which would identify an array of possible sites based on complexity, access to sufficient light levels and access to points of food sale, for example.

6.3.1 - Prioritisation of implementation

Based on the research within this thesis, it is known that there are a number of challenges to be overcome when integrating technical food systems. Although the facade-farm only exists as a prototype at this stage, it is expected that the technical challenges associated with its integration will be more complex and costly than horizontal systems such as the elevated aquaponic system. Even if the facade-farm was to be retrofitted to an existing building - i.e. a glazed second skin on an existing brick envelope - it would still require the use of expensive material such as glass and a conveyor-belt growing system to be able to harvest the crops. In contrast, roof-based technical food systems would typically rely on fixed systems within polythene tunnels. Due to the infancy of the practice within high-density cities, it would be advisable to maximise the potential of the least complex and least costly food systems initially, to simultaneously reduce expenditure, gain support and increase revenue streams. Therefore, the potential integration of roof-based technical food systems should be considered initially, with facade integration occurring at a later date. This could manifest as a succession of simple polytunnels on rooftops - similar to the polytunnel used in the elevated urban farm - to kick-start urban food production and to start to initialise the creation of the new supply chains that urban agriculture will ultimately depend on in the future.

6.3.2 - Interface with food networks

One of the more essential aspects of urban agriculture, which is usually forgotten when focussing on the applicability of urban food systems, is the access to a market in which the food can be sold. Demand for the food grown is a key requirement for the successful integration of urban agriculture because without demand for the food produced there would be no sale of crops and, therefore, no economic model. Growing food close to where it is wanted or needed - i.e. where it can be sold quickly - will improve the potential of technical food systems in the future to sell crops closer to the rate of production, removing the possibility of surplus or large quantities of waste as well as reducing expenditure on transport or packaging. The prospect of selling food locally will also have the largest impact on global food trade and the reduction in environmental damage, as a result of reducing the distance food travels from thousands of miles to a few steps. The adjacency of food production and food

sale will, ultimately, allow the continuous sale of freshly harvested organic fruit and veg, without the need for herbicides, pesticides, packing, freezing or refrigeration; all of which will result in the decreased demand for energy and materials as well as the reduced production of pollution and improved access to healthy foods in urban environments.

Based on this, the analysis of Manchester was taken one step further, to include the existing points of food sale within the boundaries identified as part of the light capture study. This analysis discovered that there were 54 supermarkets or convenience stores in the centre of Manchester, which would account for a direct demand for roof space of approximately 74 percent, based on a 250 metre catchment area per supermarket (see figure 6.22). As a result of this, food grown within this area of demand would never travel further than 250m to its point of sale, if the vertical travel from the rooftop down to ground-level was not taken into consideration. The resulting stepped gradient map, shown in figure 6.23, identifies the rooftops that would be in highest demand if the catchment area of 250 metres was employed across the centre of the city.

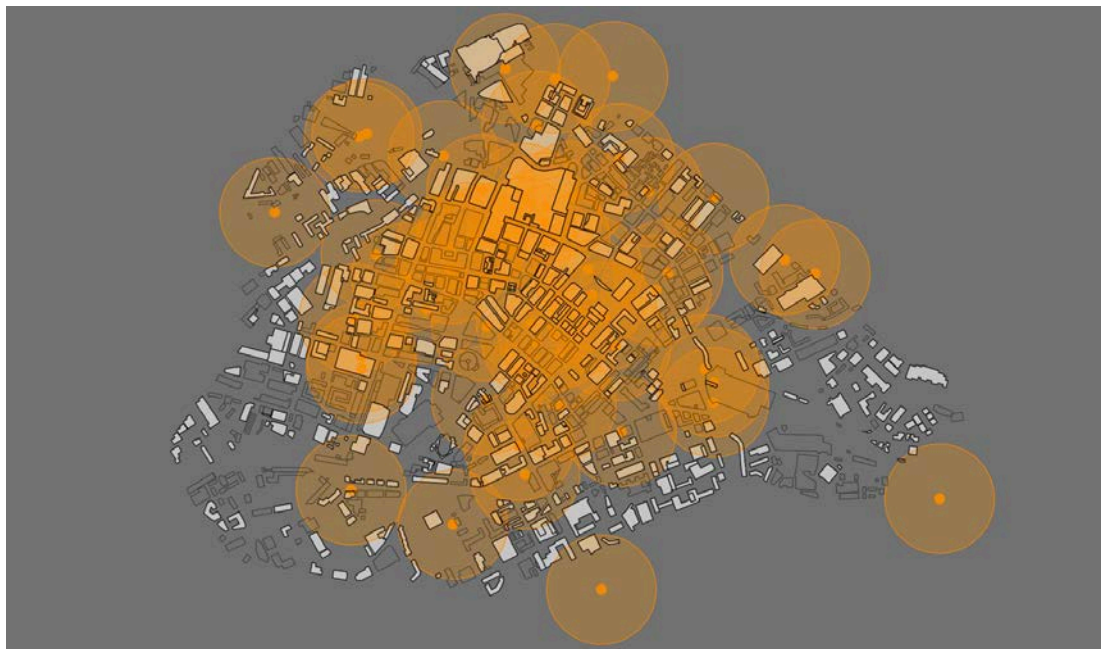


Figure 6.22 - The location of 54 supermarkets within the city of Manchester with a 250 metre catchment area

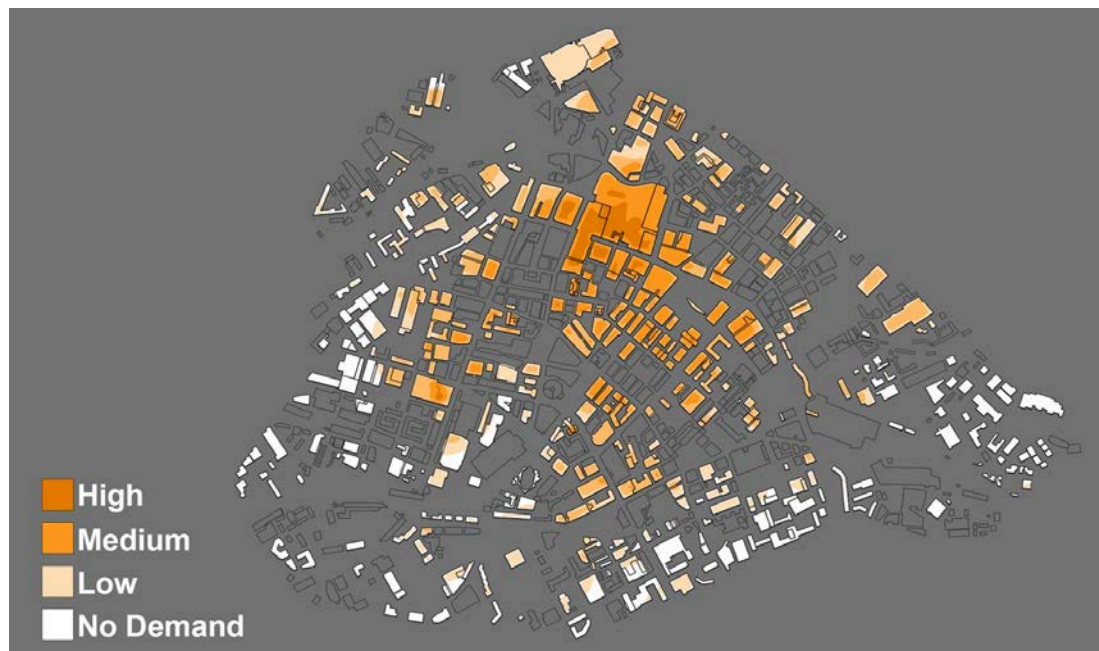


Figure 6.23 - Stepped gradient map of potential food demand in Manchester

6.3.3 - Framework of integration

When the availability of light is combined with the demand for roof space, a third map is produced. This map, which is shown in figure 6.24, identifies areas that have both excellent light capture and good access to points of sale in mint green, through to areas that have poor light capture and reduced access to points of sale in dark green. The resulting analysis identifies that the areas in mint green are prime locations for initial building integrated technical food systems because they have both good light capture and access to many different points of sale; maximising the probability of food being sold within 250-metre radius, as well as growing the demand for urban food before other sites are developed. Reciprocally, areas in dark green are places that should be developed at a later date due to the fact that they are not located close to points of food sale in addition to experiencing lower levels of light capture. This map, therefore, forms an integral part of urban analysis and acts as a potential framework for the implementation of building integrated technical food systems within the city of Manchester, whereby the mint green areas are developed first and the dark green areas are developed last; leading to the development of a city that has a visual symbiotic relationship with the ecosystems that are integral to its future prosperity.

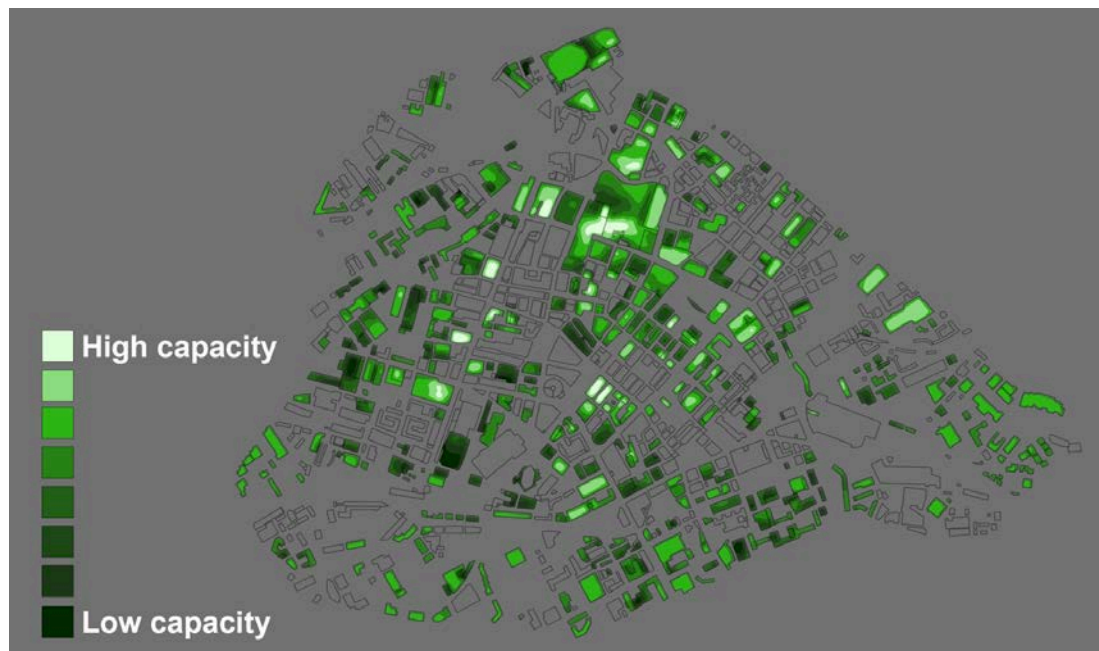


Figure 6.24 - Framework of rooftop integration based on light capture and adjacency to points of food sale

6.4 - Calculating the productive capacity of Manchester

The annual light capture analysis of Manchester proved that all of the flat roofs within the boundaries of the study could support crop growth for at least ten months of the year. Based on this it can be calculated that the 76 hectares of flat roof space within the city would be capable of growing approximately 20.2 million crops at any one time based on 26.66 crops per square metre, which is the metric of productivity taken from the elevated aquaponic system. Extrapolating this throughout the year, Manchester could produce up to 80.8 million crops per annum - based on four harvest per year - which would be worth £161.6 million per annum; based on a sale price of £2 as per the sale values achieved from the food shop adjacent to the elevated aquaponic system.

The annual light capture also identified that although the vertical surfaces of the city accounts for 310.6 hectares of the total surface area of the city, only 45 percent of that area is suitable for crop growth. This is due to the fact that 20 percent of the city's vertical surface area is overshadowed, as a result of close proximity to other

buildings - i.e. along tight streets or alleyways - and 35 percent of the vertical surface area faces between north-east and north-west; never receiving any direct sunlight as a consequence. In certain instances - such as a north-facing facade on a tight street - these two categories coincide. Although capable of supporting plant life during the brighter and warmer months, all north facing facades would be collectively titled 'additional growing space' due to their orientation and the fact that east, south and west facades would be more effective at growing crops. Therefore the overall productive area of vertical surfaces in the city of Manchester is calculated to be 167.7 hectares, not including the 86.9 hectares of north facing facades. Based on the productivity metrics of the facade-farm - i.e. 15 crops per square metre - it can be calculated the vertical surfaces of the city of Manchester would be capable of producing 25.2 million crops at any one time. Based on four harvests per year, 100.8 million crops could be grown per annum on the vertical surfaces of Manchester with a sale value of £201.6 million based, again, on the sale value of £2 per crop. Therefore, the inner urban area of Manchester is anticipated to be capable of producing 181.6 crops per annum - based on four harvest per year - which would be worth £363.2 million per annum; based on a sale value of £2 per crop.

6.5 - Estimating the productive capacity of all UK cities

As previously mentioned, the method utilised to calculate the productivity of all UK cities as a whole is dependent upon the data gathered from the analysis of Manchester. This is because the productivity of Manchester will be multiplied by the collective inner urban area of all sixty-six UK cities, to determine how many crops could be grown nationally through the use of naturally-lit building integrated technical food systems. The analysis of Manchester concluded that the city was capable of producing 181.6 million crops per annum - based on four harvests per year - on a geographic area of approximately 360 hectares; i.e. hectares that are viewed in plan. It can, therefore, be calculated that for every hectare of land Manchester sits on, it is capable of producing 504,444 crops per annum through the implementation of naturally-lit building integrated technical food systems. For the purposes of this thesis, the productivity per geographical hectare will be rounded to 500,000 crops per annum for the purposes of simplicity and to allow for a small contingency. To reiterate the points previously made, the following method of analysis is to be viewed

as a broad starting point for continued discussions relating to building integrated technical food systems and urban agriculture as a whole. The findings within this section are not intended to be a definitive answer to how much food the UK can grow as a result of urban agriculture. Instead, the findings of this section are to be viewed as a jumping off point from which future research can build on and improve in the future.

The method utilised to determine the inner urban area of the city of Manchester - i.e. by defining natural vehicular breaks - is not a universally adopted method of measurement and in many other cities around the country, these natural breaks are simply not there. Hence, to calculate the total inner city urban area of all UK cities for this study, the inner urban area of each of the sixty-six UK cities would need to be calculated individually. For this to occur, Google Earth would be used because it allows the drawing of polygons to measure both area and perimeter. Although the accuracy of the study would be improved through the use of Autodesk AutoCAD, it would be troublesome to visually determine the inner urban area of any given city without the use of aerial photography. As a result, the perimeter of the inner urban area for each city would be determined based on subjective assumptions relating to building size, height and density, as well as natural boundaries created as a result of infrastructure, industry or low-rise housing.



Figure 6.25 - Example of inner urban area analysis - Newport, 19 Hectares

Once each and every inner urban area had been determined, it could be seen that there is a huge amount of variation between the sixty-six cities within the UK. For example, the conurbation formed between the city of London and city of Westminster with the addition of London's financial district covers an area of approximately 1370 hectares, whereas St. David's in Wales has no discernible urban centre. Stoke-on-Trent is a city of six towns, which each individually cover an area of between 4 hectares and 40 hectares and collectively cover a total area of 84 hectares, with the city of Wells estimated to have the smallest inner urban area of all UK cities of 6 hectares. As a result of this study, it can be concluded that the cumulative inner urban area of the UK is approximately 5,486 hectares. The boundary and area of each city has been provided in Appendix S.

Based on the cumulative inner urban area of the UK - i.e. 5,486 hectares - and the estimation that cities can produce approximately 500,000 crops per geographic hectare, it can be determined that the productive capacity of naturally-lit building integrated technical food systems in the UK would be approximately 2,743,000,000 crops per annum. Based on the average weight of an organic Batavia lettuce of approximately 0.35 kilograms (Heimler, et al., 2012), it can be calculated that naturally-lit building integrated technical food systems in the UK could produce a maximum of 960,050 tonnes of food per annum; estimated to be worth approximately £5.5 trillion per annum, based on a sale value of £2 per crop as previously discussed. Although such massive figures are indeed impressive, it is the impact this food production has on UK food security and the mitigation of ecological damage which are the critical metrics associated with research question two.

In total the UK consumes 969.69 kilograms of food per capita per annum (FAO, 2017) giving an estimated total UK food consumption of approximately 63.6 million tonnes per annum; based on a population of 65.6 million people (ONS, 2016). Therefore, it can be calculated that naturally-lit building integrated technical food systems and the 960,050 tonnes of food it is capable of producing would be capable of feeding 990,240 people, which is equivalent to 1.5 percent of the total food consumption of the nation. Although the contribution of naturally-lit building integrated technical food systems to UK food security is very small, its impacts are impressive when considering that such an initiative could feed nearly one-million people per annum and could lead to ecological and environmental savings.

The greenhouse gases associated with food grown abroad was estimated to be 21.9 million tonnes of CO₂e in 2008 (de Ruiter, et al., 2016). As a result of food produced by naturally-lit building integrated technical food systems in the UK this value would reduce by approximately three percent - due to the fact that the UK imports approximately half of its food per annum - which would result in an ecological saving of 659,000 tonnes of CO₂e per annum. This saving is comparable to taking 832,700 cars off road in the UK, based on the average CO₂ emissions per kilometre of newly registered cars between 2003 and 2015 - i.e. 150 grams of CO₂ per kilometre (Department for Transport, 2015) - and the average annual car travel distance in 2016; i.e. 3289 miles (5,261 kilometres) (Department for Transport, 2017a). This ecological saving would also be the same as removing 6,974 fully loaded thirty-ton articulated lorries from UK roads based on the average travel distance of 30 ton articulated heavy goods vehicles between 2004 and 2016 - i.e. 59,000 kilometres (Department for Transport, 2017b) - and the average CO₂ emissions per kilometre of Euro-class I, II, III and IV heavy goods articulated vehicles: i.e. (Zanni, et al., 2008).

Food grown for UK consumption both domestically and internationally requires approximately 10,922,000 hectares of land, of which 67 percent is located abroad (de Ruiter, et al., 2016). As mentioned previously, the total food consumption of the UK is approximately 63.6 million tonnes of food, which equates to a consumed productivity of 5.7 tonnes of food per hectare of agricultural land. Taking the 959,525 tonnes of food that naturally-lit building integrated technical food systems can produce, it can be estimated that this additional production of food in the UK could reduce demand by 168,337 hectares, which is roughly the same size as the Shetland Islands.

6.6 - Socio-economic benefits of urban agriculture

Although the expected contribution of naturally-lit building integrated technical food systems to UK food security is very small, the implementation of such urban food systems could lead to large economic and environmental benefits, as well as creating other supporting services such as air filtration, psychological restoration, and the creation of jobs. In fact, all forms of sustainable agricultural practices - whether soil-based or soilless - contribute to the delivery and maintenance of a wide

range of public services such as carbon sequestration, water purification and amenity value (Pretty, 2012) as well as social benefits. Through food, things like *'culture, community and identity are created, enacted and reinforced'* (Stock, et al., 2012, p.119). These attributes are closely related to the development of social capital, which describes the way in which people come together in cultural and economic life through trust, solidarity, reciprocity and exchange to form a prosperous society. The relationships between people, groups and networks can be seen as either bonded, bridged or linked, which identifies the different way people can unite to form successful societies regardless of their personal views and beliefs. The bonding of social capital refers to the interconnection of those who share similar views and beliefs, the bridging of social capital refers to the interconnection of those who do not share similar views and beliefs, and the linking of social capital refers to the positive relationships between 'the people' and the different levels of authority within society (Woolcock, 1998; Pretty, 2003). Social capital is seen as imperative to the adoption of sustainable behaviours and technologies over large areas, as well as a precursor to the sustainable management of resources and technologies (Godfray, et al., 2010).

In today's cities, issues relating to mental health and physical wellbeing are becoming increasingly important in developed countries where, for example, depression and anxiety rates have risen despite increases in economic prosperity and improved living standards. Given the projected growth in the proportion of people living in cities (ESA, 2012), it is becoming increasingly significant to understand the potential impacts of the urban context on these two indicators. The following pages aim to understand the ways in which the additional services provided by building integrated technical food systems may improve the physical, psychological and financial wellbeing of urban populations, and also represents a broad overview of the different ways in which urban agriculture can engage with cities beyond the production of food. The conclusions made, in most cases, do not aim to quantify these additional benefits but instead, aim to discuss the linkages between prevalent issues within the urban context and the additional services provided through the implementation of building integrated technical food system, or any other urban food system for that matter. Although the economics of building integrated technical food systems will be discussed further, it is not the role of the thesis to develop robust economic models. Instead, the thesis aims to use simple

methods of analysis to determine the impact of such systems on local economies and job creation; developing a basic understanding from which other studies can build from in the future.

6.6.1 - The negative effects of cities on urban populations

Urbanisation is a process closely linked with economic development, but its impact on health and wellbeing can, in some instances, be dramatic. non-communicable diseases (NCDs), which consists of mainly cardiovascular diseases, chronic respiratory diseases, cancers, and diabetes, are the world's biggest killers. More than 36 million people die annually from NCDs accounting for 63 percent of global deaths each year (WHO, 2013). The primary causes in most cases of premature death from NCDs are tobacco use, an unhealthy diet, physical inactivity and the excessive consumption of alcohol. Although urban development cannot be held responsible for these risk factors, the urban context is associated with the adoption of lifestyles that favour the development of NCDs (Van de Poel, et al., 2009). This is due in part to increased exposure to outdoor air pollution, overcrowding, crime, stressful work and social isolation, as well as the increased consumption of salt and high sugar foods, reduced physical activity, and increased tobacco use. All of which increase the risk of hypertension and obesity, leading to an increased risk of heart disease, strokes, certain cancers and diabetes (Mendez, et al., 2004). Although developed countries only account for 14 percent of the total annual deaths from NCDs, they also only account for 17 percent of the world's total population (ESA, 2015). Therefore, tackling the causes of NCDs is a shared responsibility between both developed and developing regions.

Psychological disorders

The development of psychiatric disorders, including stress and anxiety amongst other conditions, is one area in which the urban context can dramatically affect the wellbeing of an individual. Taking twenty of the highest quality studies over a twenty-year period, Peen et al. (2009) discovered there was a significant correlation between urban living and decreased psychological wellbeing. The research, utilising studies from 1985 to 2005 within high-income countries, discovered that the presence of psychological conditions, in general, were 38 percent higher in urban

areas than in rural areas. This also included for mood disorders - i.e. depression - which were 39 percent higher as well as anxiety disorders, which were 21 percent higher (Peen, et al., 2009). This could be attributed to a lack of access to natural and green environments, which has been found to increase the presence of depression and suicidal indicators by between 16 and 27 percent (Min, et al., 2017). Within the UK, the total cost of depression and anxiety in 2007 was £7.5 billion and £8.9 billion respectively (McCrone, et al., 2008). The total spent on psychological disorders in the same year - minus that spent on dementia - was £33.8 billion, which is expected to rise to £36.8 billion by 2026 (McCrone, et al., 2008). These psychological disorders, as a result of city living, need addressing to help increase the mental wellbeing of urban populations, reduce the economic strain brought about by these conditions, and to reduce the number of those affected developing more serious physical conditions. Psychological wellbeing is of huge importance within urban environments, but it is not the only issues affecting people within cities.

Air pollution

The adverse effects of inhaling air pollution are well known and as such air quality is another area of concern within cities. Air pollution is primarily comprised of particulate matter (including sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water), ozone (O₃), nitrogen dioxide (NO₂) and sulphur dioxide (SO₂). Urban air pollution can be responsible for such problems as Chronic Obstructive Pulmonary Disease (COPD), which is a collection of lung diseases; including chronic bronchitis, emphysema and chronic obstructive airways disease. Within the UK, air pollution is estimated to reduce life expectancy by seven to eight months (Environmental Audit Committee, 2010) and within Europe, over 100,000 deaths are recorded per year as a direct result of exposure to fine particulate matter (WHO, 2003). Air pollution ultimately leads towards poor health and loss of life - both of which affect physical and mental wellbeing - but the cost of treating these issues is also very high. For example, the total direct cost of COPD to the NHS in the UK is over £800 million per annum, with the indirect cost of lost productivity to employers and the economy estimated to be £3.8 billion per annum (NHS Medical Directorate, 2012). The total cost of health problems related specifically to particulate matter are even higher; estimated to be between £9.1 and £21.4 billion per annum (DEFRA, 2007).

High levels of air pollution can also exacerbate symptoms found within asthma sufferers and in some cases, can lead to fatal asthma attacks. It is estimated that an additional 100 million people will be diagnosed with asthma by 2025 (Masoli, et al., 2004), which currently accounts for approximately 250,000 annual deaths worldwide (WHO, 2007). It is also expected that urban air quality will continue to deteriorate globally if no new policies are implemented and outdoor air pollution - i.e. particulate matter and ground-level ozone - is projected to become the top cause of environmentally related deaths worldwide by 2050 (Organisation for Economic Cooperation and Development, 2012). Hence, the improvement of air quality is critical to reducing premature death and improving quality of life.

Obesity and diabetes

Although not necessarily exacerbated within urban areas (Peytremann-Bridevaux, et al., 2007; Befort, et al., 2012) obesity is quickly becoming a global epidemic. Diabetes, on the other hand, is projected to increase globally as a result of urbanisation (Wild, et al., 2004). In 2012, an estimated 62 percent of adults were overweight in England; 24.7 percent of which were obese and 2.4 percent noted as severely obese (Public Health England, 2014a). Consequently, diabetes is also on the rise. In 2013, 2.7 million adults were diagnosed with diabetes in England; an increase of 137,000 people from the previous year (Prescribing and Primary Care Team, 2013). Within the UK, 10,000 premature deaths per annum are linked to obesity (Faculty of Public Health, n.d.) with type 2 diabetes accounting for 23,300 deaths per annum in England alone (Public Health England, 2014b). As with the psychiatric issues previously noted, and the health issues caused by air pollution, there is a high cost associated with caring for people with these conditions. Obesity costs the UK £4.2 billion pounds per annum and type 2 diabetes accounts for expenditures of £13 billion per year (Public Health England, 2014b). Only through challenging the risk factors associated with NCDs - specifically physical inactivity and poor diets - will the prevalence of obesity and diabetes start to decline, bringing with it healthier populations who live longer and happier lives.

Non-communicable diseases and urban agriculture

Due to the linkages between lifestyle choices and the primary risk factors of NCDs, the majority of premature deaths associated with these conditions are largely preventable by tackling the associated risks (WHO, 2013). Although it can be argued that these risk factors cannot be directly resolved as a result of building integrated technical food systems, or urban agriculture as a whole, the integration of agriculture within urban environments can promote alternative lifestyles to those currently offered within cities, which may help to reduce the impacts of the risks indicated.

6.6.2 - Human wellbeing and the impact of urban agriculture

Human wellbeing consists of security, the necessary materials for a viable livelihood (food, shelter, clothing, energy, etc., or the income necessary to purchase them), freedom, choice, good health, and good social-cultural relations (Millennium Ecosystem Assessment, 2005). Ultimately, all aspects of human life are defined by the access to ecosystem services such as food, clean water and fresh air. If the above factors of human wellbeing are combined with the primary causes of non-communicative diseases, three distinct categories emerge in which the impact of urban agriculture can be qualified; i.e. physical health, psychological wellbeing, and financial security. The following pages will discuss how building integrated technical food systems can benefit urban societies in these three key areas so as to build an understanding of the future socio-economic cohesion of agriculture and urbanity.

Physical health - Food production

The obvious and most prevalent way in which urban agriculture can affect physical health is through the production of fresh, and possibly organic, crops. As previously mentioned, it is estimated that urban agriculture can produce 960,050 tonnes of food across the UK as a result of rooftop and facade-based technical food systems. Such levels of productivity could potentially improve access to healthy foods and potentially increase the consumption of fruit and vegetables within urban contexts.

Over the past few decades, there has been a trend in intensive food production that makes use of the cheapest ingredients possible. Although this has brought many people out of food poverty, it has also led to a decrease in human health (Alston et al., 2008). It is now believed that intensively produced high-calorie foods suppress the need for humans to eat plant-based diets and more worryingly, is that the sales of these quick energy release foods are increasing and even more so in developing nations (Blouin et al., 2009). Such foods typically contain excessive levels of sodium, which is the leading cause of ischaemic heart disease and hypertension, and it is estimated that up to a billion people already ingest superfluous quantities of salt worldwide (Cordain et al. 2005). Due to these cheap foods, poorer sub-populations can readily access energy-dense foods. However, this practice culturally and socially excludes many people from dietary diversity (Hawkes, 2006) which results in a reduced intake of micronutrients that can be detrimental to human health, such as the insufficient intake of flavonoids and other antioxidant compounds (Butler, et al., 2012). As a result, it is estimated that half of the world's population is currently deficient in the micronutrients required to achieve good health (Butler, 2012).

Even for affluent populations, a good diet can be elusive. This is because, in many developed regions, the staple foods that human ancestors depended on have been altered enormously through breeding and processing before they are eaten today. These once low-fat high-protein foods now contain excessive energy, which can lead to issues relating to obesity and diabetes. This nutritional ignorance, which was not relevant to the early ancestors of humans, is now a vulnerability for modern people who buy highly processed foods (Butler, et al., 2012). In the search for optimal nutrition, large numbers of people have taken to consuming synthetic vitamins and fortified foods. This is despite the substantial evidence that a varied diet rich in micronutrients, especially vegetables and fruit, promotes improved health as well as lowering the risks of cancer and heart disease. Vitamin deficiencies can be harmful, but the most reliable epidemiological evidence concerning supplementary ingestion of vitamins is that they too can do harm to human health (Lawlor et al., 2004). In some cases, vitamins are taken to combat the shortfall in micronutrient uptake due to the proliferation of processed foods in developed regions. However, many of these supplements are so separated from their evolutionary context that they can, again, result in harm to human health. Some see this as an inevitable response to

the degradation in agricultural landscapes, which causes food yields to decline and nutrient levels to subside (Butler, et al., 2012).

As a result of high-energy, fatty, and salty foods, combined with an existence that requires the expenditure of fewer calories to survive than those expended by the ancestors of humans, the levels of obesity, diabetes and heart disease are increasing across the globe. However, when people are only given the option to buy foods that are heavily processed they lack the freedom to decide to eat healthily. Therefore, access to the right food - i.e. food access - is an issue that can affect all populations, not only those who lack it. In post-industrialised or decaying urban environments it can sometimes be difficult for those who are less fortunate to access the right food. This creates a cycle where people become unhealthy, overweight and unhappy. Wallinga (2010) draws a comparison between the US 'cheap food' policies and the increasing rates of childhood obesity in the country due to financial structures that reward food processors who produce fatty, sugary foods with minimal nutritional value. Therefore, without access to the right food, many people can feel stuck in this cycle, which ultimately transcends generations, creating more unhealthy and unhappy people.

Taking the aforementioned primary causes of non-communicable diseases - tobacco use, poor diet, physical inactivity and alcohol use - it can be argued that the integration of agriculture within urban environments is capable of directly and positively affecting some but not all of these issues. For example, urban agriculture cannot directly affect excessive alcoholism or reduce the use of tobacco. The integration of urban agriculture can, however, help promote healthier lifestyle choices through the production of healthy organic foods as well as improving food access for those who need it the most. In many of the larger cities across the UK, affluent areas are flanked by areas of deprivation. Both sets of communities exist within the same space, but the dietary diversity of one, will not be the same as the other. Urban agriculture enables the opportunity to combat both poor dietary diversity and poor food access through the implementation of a single initiative. In theory, any crop can be grown within a technical food system, and as long as the choice of a healthy lifestyle is there for all to choose the integration of technical food systems upon existing buildings could potentially lead towards healthier and happier urban populations.

Physical health - Air pollution

Adopting the same area studied for the lighting study of Manchester, further investigation was undertaken to analyse the provision of green space within the city. It can be seen, in figure 6.26, that the current proportion of green space within the city is particularly low. The city centre of Manchester covers an area approximately 360 hectares in size, of which green space accounts for only 24.2 hectares; approximately 6.7 percent of the study area (see figure 6.26). This collective urban green space also includes for public green spaces which occupy approximately 5.4 hectares of the city; accounting for 1.5 percent of the study area. Urban green spaces are key to the improvement of urban air quality because they not only help with carbon sequestration and oxygen production, but they also aid in the reduction of particulate matter, and can in some cases absorb ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2).

Taking into account only horizontal food systems on flat roofs of the city, urban agriculture would add 76 hectares of green space to the study area, as shown in figure 6.27. Although the area of vertical surfaces capable of supporting crop growth within the city of Manchester is estimated to be 167.7 hectares, the productivity of vertical systems is expected to be 56 percent less than the productivity of horizontal systems; i.e. 15 crops/m² compared with 26.66 crops/m². Therefore, the relative comparative area for crop growth upon vertical surfaces would be 94 hectares. If the areas of green infrastructure for both horizontal and vertical surfaces are combined, the total cumulative addition of green infrastructure within the city of Manchester through the implementation of building integrated technical food systems would be 170 hectares; increasing green infrastructure within the city from 24.2 hectares to 194.2 hectares, which is an increase of 702 percent. As a result, the cities capacity to sequester carbon, produce oxygen, and remove particulate matter and other damaging chemical compounds from the air would be increased by a factor of eight. The creation of cleaner urban environments as a result of building integrated technical would not only better protect those suffering from respiratory diseases, but it would also potentially lead to the reduction in the development of such diseases, as well as potentially promoting physical activity across the city through the creation of cleaner and more engaging urban spaces.



Figure 6.26 - Current provision of green space within the city of Manchester



Figure 6.27 - Potential provision of green space as a result of building integrated food systems with the city of Manchester

Psychological wellbeing

As mentioned previously, depression and anxiety disorders are found to be 39 percent and 21 percent higher respectively in urban areas (Peen, et al., 2009) and this, along with lack of connection to ecosystem services, can have an adverse effect on the wellbeing of an individual. Urban agriculture - beyond its primary role as a producer of food - can contribute to reductions in stress, depression and anxiety through the increased provision of green space within cities. When the benefits of green spaces are combined with the effects of improved air quality and the provision of more engaging public spaces, the cumulative effect can be substantial.

The effects of green space within urban environments on both physiological and psychological indicators have been researched extensively over the past twenty years. The consensus is that the exposure to natural environments has a number of benefits over the exposure to urban environments. The underlying theory relating to this effect suggests that humans have evolved a positive psychological response to unthreatening natural environments, to allow fast and effective recovery from the stress response. It is believed that modern humans retained this positive response to natural environments and it is still as crucial today as it was many millennia ago (Ulrich, 1993). In this context, restoration is defined as the process of recovering physiological, psychological and social resources that have become diminished in efforts to meet the demands of everyday life (Hartig, 2007). These restorative qualities include, but are not limited to, the reduction in blood pressure, levelling of heart rate, reduction in muscle tension and reduction in stress hormone levels as well as the strengthening of the immune system (Hartig et al., 2003; Park, et al., 2010, Husqvarna Group, 2013). The greater an individual's need for restoration - i.e. the more stressed and/or fatigued they are - the more they benefit from exposure to natural environments (Ottosson, et al., 2008). There are even opportunities for 'micro-restorative' experiences during day to day life when natural environments are view through a window, for example. Although brief, these micro-experiences can mount up to result in a measurable cumulative benefit (Kaplan, 1993).

The introduction of building integrated technical food systems to the study area of Manchester city centre, as mentioned previously, would increase green space within the city by over 700 percent; adding 170 hectares of restorative infrastructure to the

city. Although the majority of this newly created foliage would be inaccessible to most, the views out from buildings within the city would be transformed from views of glass, concrete and steel to a sea of vegetation spreading across rooftops, spilling down facades and engaging with the public realm. This in itself would bring with it a multitude of opportunities for micro-restoration throughout the day as well as opportunities for full psychological restoration through the creation of vegetative social spaces. To provide tangible restorative opportunities within the city, a proportion of urban agricultural production at roof level could be considered as 'multipurpose space'; functioning as both farm and social space. If, for example, ten percent of urban agricultural production upon flat roofs was also utilised as public space the allocation of accessible green space within the city of Manchester would increase by 70 percent from 24.2 hectares to 41.2; a significant increase in terms of both area and social wellbeing. The implementation of building integrated technical food systems would also create opportunities for social spaces and public engagement at ground level through the creation of markets, shops and cafes, possibly including such elements as facade-farms which employ a 'pick-your-own' policy at street-level. Social engagement is a prerequisite for psychological wellbeing and the opportunity to create a multitude of connected social spaces, as well as restorative and micro-restorative environments, through the integration of technical food system upon existing buildings, becomes a realistic proposition in future cities which embrace all forms of urban agriculture.

Physical activity, although primarily linked with physical wellbeing, also has a profound effect on the psychological wellbeing of an individual. Exercise is key to mental wellbeing, but within urban environments, exercise in the traditional sense is hard to fit into daily life. That being said, even brief five-minute spells of green exercise can lead to large benefits (Barton, et al., 2010). Again, those who are in the most need of help improve quicker with regards to mood and self-esteem as a result of green exercise (Roe, et al., 2011). Consequently, green exercise projects are increasingly seen as a valuable form of treatment for mental health problems.

The integration of urban agriculture can, therefore, improve the provision of green spaces within cities, which have the potential to benefit all people - especially those struggling with psychiatric disorders - as a result of increasing the likelihood of encountering positive and reasserting experiences. Spending time in green

environments, whether combined with physical activity or just for passive relaxation, has a positive effect on a range of physiological and psychological indicators, including blood pressure, levels of stress hormones, immune system functionality, mood and self-esteem; demonstrating the potential key role agriculture could play in future urban development.

Financial security

Ecosystem services are vital to the wellbeing of urban populations, but they are also key to a successful economy; providing the resources needed to produce goods and services, as well as absorb and process unwanted byproducts. Environmental assets and services also help contribute to managing economic risks (Everett, et al., 2010). Urban agriculture has the potential, therefore, to not only provide ecosystem services such as air-filtration and food production but also to create economic opportunities within cities; thus contributing to the financial security of urban populations. It is estimated that the city of Manchester can grow approximately 180 million crops per annum, achieving a sale value of £360 million per annum. Such massive levels of crop production would require a substantial workforce; creating jobs from seedling planters to operations managers across the city.

As mentioned at the start of this paper, it is not the role of this thesis to develop robust economic models for urban agriculture. Instead, the thesis aims to use simple methods of analysis to determine the impact of urban agriculture on local economies. The profits, running costs and cost of human capital of any company or business are extremely sensitive to external pressures and complex to calculate. Hence, simple existing information will be used to inform these metrics at this stage of the research. A supermarket chain within the UK will be used to help inform operational profits, a study of fortune 500 companies in the United States will be used to determine the cost of human capital and the remaining money will be assigned to running costs such as power, costs of repairs and advertising. The expenditure on human capital will then be combined with the UK wage distribution - i.e. the average wage earned per one percent of the population - to calculate the number of jobs that could be generated as a result of building integrated technical food systems within the city of Manchester.

Tesco is a large supermarket chain in the UK and reported operating profits of 9.2 percent in 2015 (Tesco, 2015). If this is applied to the projected turnover of urban agriculture in Manchester - i.e. £360 million - approximately £33 million would be set aside to invest in new technologies, train new staff, engage in social activities and ultimately protect the business model. The percentage spent on human capital is approximately 70 percent of total expenditure within large businesses (Human Capital Management Institute, n.d.), which would account for £229 million of the expected annual turnover; leaving £98 million over to pay for energy, repairs, rental of roof and facade space, advertising, etc.. If the value of £229 million for the cost of human capital is combined with the average distribution of wage per one percent of population within the UK (H.M. Revenues and Customs, 2015) the potential job creation of building integrated technical food systems within Manchester can be calculated. For example, the 1st percentile of the labour force in the UK earn on average £8,370 per annum, which accounts for 0.3 percent of the total wage bill of the UK. On the other hand, the 99th percentile of the workforce earn on average £150,000 per annum, which accounts for 5.5 percent of the total wage bill of the UK (H.M. Revenues and Customs, 2015). By using the same proportions of wage spend per one percent of the population and applying it to the £229 million available for job creation in Manchester, it can be calculated that a maximum of 8,385 jobs would be created within the city at varying levels of importance and income. A sample of the data has been provided in table 6.3 indicating 84.7 jobs are created for every one percent of the workforce, equalling 8,385 jobs in total; or one job per £42,933 of food sold. It can, therefore, be assumed that urban agriculture can have a substantial impact on both job creation and the local economy. With £30 million per annum to invest in local community projects and technological advancement, urban agriculture could become socially, culturally and economically significant in the future. It has been previously noted in this chapter that the UK has the potential to produce £5.5 trillion worth of food per annum as a result of the implementation of building integrated technical food systems. Utilising the key metric from that the city of Manchester - i.e. that one job is created for every £42,933 of food sold - it can be calculated that 128,104 jobs could be created across the UK as a result of building integrated technical food systems. It should be noted, however, that both the estimations presented for Manchester and the UK do not account for jobs lost elsewhere along the food distribution chain, which means the net gain in employment opportunities could be less than those stated here.

Table 6.3 - Sample data of job creation in Manchester as a result of urban agricultural integration (UA = Urban Agriculture)

Percentile of Workforce	UK Average Annual Wage	Percentage of UK wage bill	Money available to UA	Money for job creation in UA	No. of jobs created by UA
1st	£8,370	0.31	£229,000,000	£708,949	84.7
10th	£10,900	0.40	£229,000,000	£923,244	84.7
20th	£13,100	0.48	£229,000,000	£1,109,586	84.7
30th	£15,400	0.57	£229,000,000	£1,304,399	84.7
40th	£18,000	0.67	£229,000,000	£1,524,623	84.7
50th	£21,000	0.78	£229,000,000	£1,778,726	84.7
60th	£24,800	0.92	£229,000,000	£2,100,591	84.7
70th	£29,700	1.10	£229,000,000	£2,515,627	84.7
80th	£36,700	1.36	£229,000,000	£3,108,536	84.7
90th	£49,200	1.82	£229,000,000	£4,167,302	84.7
99th	£150,000	5.55	£229,000,000	£12,705,188	84.7
TOTAL JOBS CREATED = (84.7 x 99) = 8,385					

6.6.3 - Summary of urban agriculture on the wellbeing of urban populations

The role of any urban food system is primarily to produce food, but they can also provide many other additional services. Urban environments can drastically affect the physical and psychological wellbeing of an individual. Air pollution, poor diets, physical inactivity, depression, anxiety and financial insecurity are all issues which affect the wellbeing of individuals, and urban agriculture can help remedy these issues to varying degrees. In the case of Manchester, England the implementation of building integrated technical food systems could increase vegetation within the city by over 700 percent; i.e. from 24.2 hectares to 194.2 hectares. In doing so the ability to sequester carbon, produce oxygen, reduce particulate matter and to varying degrees reduce ozone, nitrogen dioxide, and sulphur dioxide is increased. All of which reduce the probability of urban populations suffering asthma attacks or developing chronic obstructive pulmonary diseases. The reduction in people with

respiratory diseases not only saves money by reducing patient numbers but more importantly, leads to healthier and happier urban populations. Additional green vegetation within cities, even if not always accessible to the general public, has the potential to aid in reducing depression and anxiety through the restorative healing powers of natural landscapes, which could also aid in promoting exercise in urban environments through the use of green corridors, engaging public spaces, and the production of cleaner air. Finally, building integrated technical food systems can produce large quantities of food, which can improve access to fresh healthy produce and potentially decrease the issues associated with obesity and diabetes, in addition to creating employment opportunities within cleaner, more engaging cities.

7.0

CONCLUSIONS

7.0 // CONCLUSIONS //

In the previous chapter, the data collected from the elevated aquaponic system and the facade-farm prototype was combined with light capture data to estimate the productive capacity of the inner urban area of Manchester, England. This data was then used as a basis to calculate the productive capacity of all the inner urban areas in the UK to gain a better understanding of the potential impacts building integrated technical food systems may have on UK food security, as well as the mitigation of ecological damage and the wellbeing of urban populations. This final chapter brings together all the knowledge collected and generated in the thesis to arrive at some conclusions relating to building integrated technical food systems and urban agriculture as a whole.

7.1 - Overview

Although cities are man-made techno-centric environments, they depend entirely on the access to ecosystem services well beyond their municipal boundaries to function and survive. The practice of importing food, although commonplace in today's world, not only leaves cities vulnerable to shock and change without warning but it also requires a vast amount of energy to grow, harvest, package, refrigerate, freeze and transport food around the globe, to ensure shelves in supermarkets main full. If cities are to become more sustainable and resilient to change it is likely that they will have to engage with ecosystem services at increasingly localised levels. Urban agriculture, in most respects, provides a possible alternative to the global food system through the production of food within or upon buildings in high-density cities to provide food where demand is highest, mitigating ecological damage and improving national food security as a result.

This thesis is based on a lineage of urban agricultural inquiry that aimed to determine and understand the technical complexities associated with integrating technical food systems within or upon existing buildings in high-density cities, to calculate the effects these systems may have on domestic food security and the

potential mitigation of ecological damage, and to explore and discuss the potential benefits such systems may bring to urban populations in the future. The role of this final chapter is not to reiterate the information contained within the thesis but instead to give clear, concise and succinct answers to the three research questions posed from the outset. The knowledge generated as a result of each research question will be documented in the following pages, along with a summary of the process utilised and the conclusions reached.

7.2 - Conclusions to the three research questions

7.2.1 - Research question one

What are the prominent technical challenges associated with integrating technical food systems within existing buildings above ground-level?

Summary of process

At the beginning of 2012, Queen's University Belfast was approached to design a working urban farm for the Manchester International Festival 2013; a celebration of socially engaging and cultural art, which showcases original and inspirational projects. Queen's University Belfast put forward a visionary design that would convert an ex-industrial post-war factory in Salford, England into an urban laboratory for sustainable food production. The decision was made early on that the crops would be grown through the use of an aquaponic system, which mimics the naturally occurring symbiosis created between fish, bacteria and plants. Aquaponic systems, unlike hydroponic systems, create a self-regulating ecosystem, which reduces human interaction. Due to the presence of fish, such systems are also capable of utilising the waste streams of cities. This can be achieved through the provision of vermicomposting systems, which converts cardboard and vegetable waste into worms that can be fed to the fish. Due to the self-regulating qualities of an aquaponic system, the water within the system becomes a commodity that is nurtured and only replaced in extenuating circumstances or during deep cleaning. Consumption of water is therefore much lower when compared with hydroponic systems and traditional irrigated soil-based practices.

In order to better understand the technical challenges associated with the integration of large urban food systems a small-scale aquaponic prototype was constructed initially, to experience the design process that is required when creating a working ecosystem, and to understand the inner workings of how such an ecosystem operates within the bounds of the technical materials that encapsulate it. The knowledge acquired from the small-scale aquaponic system was then utilised to inform the design and construction of a larger aquaponic system - otherwise known as the 'elevated aquaponic system' within the thesis. The aquaponic system is referred to as 'elevated' because it was constructed above ground-level; spanning between the top floor and rooftop of the existing building in order to maximise productivity. Typically, large aquaponic systems when located within buildings are placed at ground-level due to the weight of the water required to fill the fish tanks and the filtration unit. Due to this inherent weight, it can be unsafe to locate aquaponic systems above ground-level within or upon buildings because the typical construction of internal floors and rooftops are not capable of supporting such heavy loads.

The completed aquaponic system had to be redesigned multiple times, as a result of structural surveys and advice from accredited structural engineers, which saw the major elements of the system located above structural steel members to minimise the stress of the floor and roof slabs. The delivery of aquaponic system was only possible due to the dedication and hard work of the design team, structural engineers, and the volunteers from both Queen's University Belfast and the local area who helped construct the system. The completed elevated aquaponic system proved that large aquaponic systems can be integrated into the existing infrastructure of today's cities above ground-level, and highlighted the technical difficulties that would face similar systems in a similar context, which was the primary purpose of research question one.

Knowledge acquired

One of the primary aims of this thesis was to determine the prominent technical challenges associated with integrating a technical food system within an existing building. The decision to design and construct an aquaponic system, as opposed to a hydroponic system, raised the complexity of the project due to the additional

weight required to fill the fish tanks and the filtration unit. The collective weight of the twelve fish tanks when filled with water was close to eleven tonnes, which is a significant additional load to place within any building. Although the concrete beam and block floor was capable of supporting 3.5 kN/m² (approximately 350 kg/m²), as opposed to the minimum imposed load of 2.5 kN/m² (approximately 250 kg/m²) which is set by the British Standards Institution, it was still not capable of supporting the fish tanks which weighed close to 500 kg/m² when full. Simply put, the beam and block floor was not capable of supporting any of the larger individual elements of the aquaponic system in the first instance, especially when considering the urban farm had to also perform as an exhibition, with many people standing on the floor at any one time. The estimated total weight of the system was in the region of 15 tonnes. The fact that the building was poorly maintained was of little relevance when considering the addition of such a large weight because even the most modern of office blocks or residential towers are not built to carry three times the minimum implied loads specified by the British Standards Institution. Therefore, the most pressing technical challenge associated with the development of the project was ensuring that the aquaponic system could be safely supported by the structure of the building.

This challenge was overcome through close communication with structural engineers at the BDP, who worked alongside the design team to ensure the structural integrity of the building was maintained. Through detailed calculations, it was found that although the floor construction was unable to support the large weight of the fish tanks and filtration unit, there was additional structural capacity in the primary steel beams and steel columns. Therefore, the twelve fish tanks sat directly above four primary beams - in the shape of a square - which were supported by steel columns at each corner. The filtration unit also sat above a primary beam which was connected to a structural column at either end. This, therefore, allowed the forces associated with the elevated aquaponic to bypass the weak floor and travel directly into the foundations. The only structural alteration internally that was required was the addition of a small steel plate that was welded between the two flanges of the L-brackets that connected the beams to the columns, to reinforce them as it could not be proven mathematically how much load they could support.

Due to the failing lintels above many of the windows, it was necessary to replace these with steel lintels that would allow the weight of the roof to bypass the original concrete lintel and traverse into the exterior brickwork. This would allow the roof of the building to be utilised for the project without incurring any further structural damage, and more importantly, without posing any danger to workers or visitors. The use of these steel lintels also served a secondary purpose; to support the suspension of the south-facing grow-bags, which again, allowed another element of the aquaponic system to bypass the weak beam and block floor. Much like the floor beneath, the roof construction was too weak to be able to support the larger elements of the system safely. Therefore, the polytunnel needed to connect directly into the steel frame of the building to bypass the roof. This was achieved through the use of two large steel girders, which ran along the two longest edges of the polytunnel. This allowed the weight of the polytunnel, and the wind loading it would endure throughout its lifetime, to bypass the roof entirely and pass directly into the foundations. The only part of the aquaponic system that was not supported primarily by the steel frame of the building was the lightweight NFT system, which was deemed safe by the structural engineer to be supported directly by the roof. This is due, in part, to the depth of water running along each of the 34 NFT channels, and the relative lightweight structure of the NFT system, which was primarily constructed from softwood and plastic gutters. The largest constraint in delivering the project was negotiation the structural limitations of the building's structure in a safe manner, which played a key role in how the elevated aquaponic system was arranged and how it functioned. The key metrics for the elevated aquaponic system can be seen below.

Elevated aquaponic system metrics

Productivity	26.66 crops/m ² per harvest
Initial cost	£28,000
Running cost	£3,644.50 per annum
Weight	15,000 kg (approximately)
Energy use	2.5 kWh (full system)
Building alterations	Rooftop transfer beams, steel window lintels, and steel plate cleat stiffeners
Design Team	Andrew Jenkins, Natalie Hall, Greg Keeffe

During the development of the elevated aquaponics system, it became apparent that the components, chemistry and biology within the system were scalable. Hence, the elevated aquaponic system could be redesigned to occupy a small window sill or an entire city dependent on the context in question. This realisation led to the development of a facade-farm prototype; a double skinned facade that was capable of growing crops within the cavity created between the two glazed surfaces. The design for the facade-farm comprised of a double helix NFT system, along with a fish tank, mineralisation tank and media grow beds. Although only a prototype, the facade farm helped illustrate that building integrated technical food systems could exist both on horizontal and vertical surfaces of existing cities. The key metrics for the facade-farm system can be seen below.

Facade-Farm metrics

Productivity	15 crops/m ² per harvest (in elevation)
Initial cost	£300/m ² for addition of aquaponic equipment
Running costs	£28.5/m ² per annum
Weight	Currently unknown
Energy use	0.01kWh/m ²
Building alterations	Currently unknown
Design team	Andrew Jenkins, Natalie Hall, Greg Keeffe

The productivity of both orientations of technical food system would ultimately provide much needed data for the light capture analysis in research question two; i.e. that horizontal building integrated technical food systems were capable of growing 26.66 crops per metre squared and that horizontal building integrated technical food systems were capable of growing 15 crops per metre squared, based on the findings in this thesis.

Although the structural capacity of the building led to the most pressing technical challenge associated with the integration of the elevated aquaponic system, it was not the only issue that needed to be addressed. The health and safety of those operating the system and those visiting during the festival was also a concern. Early on in the development of the project the design team were made aware that

although a low risk, it was possible that *Legionella* could develop in the system, which could then be contracted by those in contact with or nearby the elevated aquaponic system. The proliferation of *Legionella Pneumophila* in water systems is the result of interrelationships between temperature, environmental micro-organisms, sediments, and the chemical composition of waters. The risk of contracting Legionnaires disease can be reduced to an acceptable level through the careful design and regular maintenance of the elevated aquaponic system. This was achieved by avoiding water temperatures between 20 degrees Celsius and 40 degrees Celsius, reducing the presence of stagnant water and sediment buildup, and reducing the likelihood of splashing water to minimise the risk of aerosol formation which helps transport the bacteria when inhaled. In addition to making the relevant changes to the elevated aquaponic system to ensure safe operation, three ultraviolet bacterial filters were also placed after each stage of the system: i.e. after the fish tanks, after the filtration unit and after the window growing system to minimise the spread of legionella, if it was indeed present. The testing for *Legionella* would also form a key section of the maintenance manual that was produced in preparation for the handover of the system, which would ensure biological activity in the water was below safe levels.

The final issue facing the integration of technical food systems within existing buildings is related to water ingress and humidity. The interiors of buildings are not designed to withstand or be exposed to, water. Typically, the issues relating to water ingress are primarily mitigated by the building envelope, along with the use of plastic pipework in the building, which keeps the interior of the building dry. Building integrated technical food systems - which are comprised of both pressurised and unpressurised water systems - however, are reliant on the movement of water within built structures to deliver nutrients to crops in both hydroponic and aquaponic systems and to maintain water quality for fish in aquaponic systems. Placing such systems within buildings not only increases the humidity and overall dampness of interior spaces - which can degrade certain materials over time - but it also increases the risk of water damage to the interior building elements, which could result in the need for significant building repair. At the very beginning of commissioning the elevated aquaponic system, there were many floods; some of which were very large and dripped through to the floor below. Although the addition of the pump logic - as part of the control system delivered by Siemens - was able to

reduce the risk of both sumps overflowing and pumps running dry, water ingress should always be considered a risk within buildings. This risk could be remedied through the use of tanking, which utilises a waterproof membrane across the entirety of the floor and a portion of the wall - creating a waterproof box - but opening doors would still allow water to flow through the building if a sufficient loss of water occurred. Only by stepping down into a room containing a technical food system, or by raising the door thresholds, could this issue be mitigated to an acceptable level.

Conclusions

The successful integration of the elevated aquaponic system proved that heavy aquaponic systems can be integrated within existing buildings above ground-level in a safe manner; which opens up a multitude of opportunities for urban food production, biocyclical urbanism and circular economies in the future. When combined with existing examples of ground-level technical food systems such as Urban Organics in Minneapolis, roof-based technical food systems such as Sky Vegetables in New York, and external ground-level community gardens such as Alice Street Community Gardens in Boston, it can be concluded that food can be grown extensively, throughout existing cities, regardless of context.

The structural limitation of existing buildings is the predominant technical challenge facing the integration of technical food systems when considering food production above ground-level and this constraint will continue to hinder, shape and determine how urban food systems look and function in the future. It should be noted, again, that there needs to be a clear distinction between growing food within or upon existing buildings safely and growing food within or upon existing buildings unsafely. Whilst it may be possible for poorly maintained or weak floor and roof constructions to support heavy food systems in the short term, there is no telling what damage these additional forces may inflict upon existing building structures. Ultimately, the safety of those that engage with the food system and the building as a whole has to be of paramount importance, which is why structural engineers should always be involved with any large-scale building integrated technical food systems; to ensure the building is capable of supporting the additional load without the risk of structural damage or structural failure. In addition to protecting people from any risks that are associated with the building, it is also important to protect them from unseen risks

such as Legionella. Although considered low risk, both aquaponic and hydroponic systems pose the risk of creating conditions in which Legionella can thrive. Therefore, it is important for all technical food systems to make the required allowances to help mitigate the risks and to conduct regular water tests, to ensure the safety of those that engage both directly and indirectly with the food system.

The issues relating to humidity, water ingress and the reduction of lettable space within cities as a result of building integrated technical food systems led to the conclusion that such systems would create fewer problems when integrated as part of the building envelope; i.e. on rooftops and/or facades. The placement of building integrated technical food system as part of the building envelope would offer many benefits over internally integrated systems such as improved access to natural light, the retention of internal lettable space, as well as reducing the risks posed by water, which would be dealt with by the building envelope much in the same way as it would deal with a heavy downpour or a humid day. Due to the risks mitigated by external technical food systems, it is believed that the opportunities presented by these urban surfaces should be explored further, in preference to internally integrated technical food systems. Rooftops especially offer a simple platform for integration - when compared to the complexities associated with facade-based integration - as long as the structural limitations of the building can be overcome. Ultimately, rooftops and facades are typically unallocated or poorly utilised space within cities and the integration of technical food systems on these existing external surfaces would reduce expenditure - when compared with a newly built urban agricultural tower - whilst maximising the potential for food production and reducing the requirement for artificial lighting. By focussing on these surface, at least in the near future, it is believed that the practice of urban agriculture and the level of understanding associated with it can improve quickly, with less time focussed on problem-solving, and more time spent on the growing of food in urban centres, so as to start collecting data on the next phases of urban agriculture such as distribution and sales.

7.2.2 - Research question two

What effect, if any, would the large-scale implementation of naturally-lit building integrated technical food systems within inner urban areas have on the food security of the United Kingdom, and how might food produced in this way help mitigate ecological damage?

Summary of process

The knowledge generated as a result of the elevated aquaponic system proved that food production can occur within and upon existing buildings, whilst the facade-farm prototype showed that food could be grown within the cavity of double-skinned facades in the future. However, not every surface in existing cities receives the same level of light capture, which would ultimately determine where crops could and could not be grown in the future. In order for conclusions to be made relating to the impact urban agriculture may have on the food security of the United Kingdom and the mitigation of ecological damage as a result, the light capture of a city - in this case, Manchester - needed to be calculated. Through the production of this data, it would then be possible to calculate what proportion of the surface area of the city received enough light to support the growth of crops. The light capture data for Manchester was generated through the use of a three-dimensional model of the city, which was produced by combining Ordnance Survey information and data relating to building heights from Land Map. Together, these two data sets enabled a three-dimensional model to be created on which digital light rays could be cast and light capture calculated. By taking half-hourly shadow maps from sunrise to sunset on the 21st day of each month, an annual light capture study for the city of Manchester could be generated. From this, it would be possible to calculate what proportion of the city was capable of supporting agricultural activities. Due to the expected complexities, and the lack of empirical data, associated with growing food on inclined planes - i.e. upon pitched roofs - these surfaces of the city were omitted from the study. The light capture of the ground plane of the city was also omitted from the study due to the focus of the thesis - i.e. building integrated technical food systems - along with the issues raised in Chapter 4.0 relating to their poor scalability as a result of intense competition for land. Once the information required was obtained, it could then be combined with the empirical data from the elevated aquaponic system and

facade-farm to determine the productive capacity of the city of Manchester. The relationship between the geographical area of the city and its productivity could then be applied to all UK cities to collectively determine the total food production of urban agriculture upon naturally lit surfaces within inner urban areas of the UK.

Knowledge acquired

The impact of building integrated technical food systems on UK food security, as a result of naturally-lit technical food systems within inner urban areas, is estimated to be 1.5 percent of total food consumption, which is equivalent to feeding 990,240 people per annum. Although the contribution of building integrated technical food systems is small, the impacts of these practices can still be impressive if they are discussed in slightly different terms. For example, the detailed analysis of Manchester illustrated that 100 percent of flat roofs and 45 percent of vertical surfaces within the city would be capable of supporting crop growth. When these findings are combined with the data from the elevated aquaponic system - i.e. 26.66 crops per metre squared for horizontal systems and 15 crops per metre squared for vertical systems - it can be calculated that building integrated technical food systems could produce 181.6 million crops per annum, at a value of £363.2 million. The broader analysis of all UK cities discovered that building integrated technical food systems within the collective inner urban area of the UK could produce 2,743 million crops per annum and be worth approximately £5.5 trillion to the UK economy. As a result of this additional food production, the area of agricultural land required by the UK would also reduce by 168,337 hectares, which is comparable in size to the Shetland Islands. The pollution associated with foreign food imports would also decrease by 659,000 tonnes of CO₂e, which is comparable to taking 832,700 cars off the road or 6,974 fully loaded thirty-tonne articulated lorries. The key metrics of this analysis can be seen on the following page.

Manchester building integrated technical food system metrics

Geographical area	360 hectares
Surface area of horizontal surfaces	136 hectares
Surface area of vertical surfaces	311 hectares
Horizontal surface available for crop growth	76 hectares
Vertical surface available for crop growth	168 hectares
Productivity per annum	181.6 million crops
Productivity per geographical hectare	504,444 crops

United Kingdom building integrated technical food system metrics

Collective inner urban area of UK cities	5,486 hectares
Productivity per annum	2,743 million crops = 959,525 tonnes
UK food consumption	63.6 million tonnes
Impact on food consumption	1.5 %
Population that could be fed	990,240 people
Reduced demand for global agricultural land	168,337 hectares
Reduction in production of CO ₂ e	659,000 tonnes = 832,700 cars, or, = 6,974 fully-loaded lorries

Conclusions

This thesis has proven that existing buildings are capable of supporting agricultural practices in their current condition - without the need for purpose-built skyscrapers that are dependent on artificial light and massive initial investment - through the integration of a working aquaponic system that spanned between the top floor and rooftop of Irwell House in Salford. Although this is encouraging for the future implementation of urban agriculture within high-density cities - or any cities for that matter - the overall impact of the practice, when considering naturally-lit technical food systems on both rooftops and facades, is very low; estimated to be 1.5 percent of total UK food consumption. Such a low impact may be considered surprising by some because cities are seen as large and expansive. However, when considering

the cumulative geographical inner urban area of the UK's sixty-six cities it can be calculated that cities only account for 0.02 percent of the landmass of the UK; based on a collective inner urban area of 5,486 hectares - as calculated in this thesis - and the UK landmass of 24.2 million hectares (The World Bank, 2017).

Based on the findings of this thesis and the cumulative landshare of inner urban areas in the UK, it is unlikely that urban agriculture will ever be able to sustain urban populations entirely or be capable of producing the 50 percent shortfall in food production that the UK would require to become self-reliant. That being said, urban technical food systems are capable of producing organic food exactly where it is needed without the use of pesticides, herbicides or any other chemical additives, without the need for packaging, refrigeration or freezing, and without the need to transport food around the globe, all whilst minimising waste, strengthening circular economies and generating £5.5 trillion for the UK economy. Urban agriculture, therefore, has to be considered as a serious driver for a change and a step in the right direction in alleviating ecological damage as a result of human consumption. Urban agriculture will, therefore, have to be considered amongst a range of other strategies to enable the UK to decrease its demand for energy and food, along with reducing its production of waste and pollution.

7.2.3 - Research question three

What are the potential social and economic benefits of implementing naturally-lit building integrated technical food systems within inner urban areas, and how might these benefits improve human wellbeing within urban environments?

Summary of process

In order to be able to understand the potential socio-economic impacts of agriculture within urban environments, the thesis focussed on both the quantitative data produced in response to research questions one and two as well as making logical arguments relating to the qualitative affects urban agriculture may have on urban populations. The quantitative data produced in response to answering research question three would rely on the use of the detailed analysis of Manchester from

research question two to help calculate the increase in green space, as well as the number of jobs that could be created within the city, as a result of building integrated technical food systems. Unlike the other research questions, the qualitative conclusions of this research question could not be answered through the construction and testing of physical experiments or by conducting virtual simulations. Instead, the potential benefits of building integrated technical food systems have to be postulated until such a time occurs that there are enough urban agricultural interventions to assimilate the true benefits of agriculture within cities. Therefore logical argumentation was utilised as the method of inquiry to draw conclusions based on some first principles derived from the conclusions to research question one and research question two. For example, the light capture analysis of Manchester allowed conclusions to be drawn relating to the proportion of horizontal and vertical surfaces that would be capable of supporting the growth of crops. If all these surfaces were used as such, it would lead to a huge increase in green infrastructure around the city. This understanding can then be linked with other known research to identify how access to, or views of urban green spaces can affect the wellbeing of urban populations. In this instance, the area of crop production becomes the first principle from which other conclusions can be built on.

In summary, the knowledge generated in answering the final research question in this thesis is a key point of understanding because it provides an insight into the possible futures of cities when urban agriculture is a reality. It is hoped that such an understanding will provide additional information to policy and decision makers when considering if and where urban agriculture should be considered and how it should be implemented. For example, if the food produced as a direct result of building integrated technical food systems is considered to be insufficient in terms of food security by decision-makers in a given city, it may be possible to gain support for such initiatives based on the creation of new jobs and the improvements in the health and wellbeing of urban populations. As a result, future discussions relating to urban agriculture are built upon a new set of drivers; relating not only to the quantities of food that can be produced but also the added benefits food production can have within any given urban environment.

Knowledge acquired

The focus of research question three was to understand the ways in which urban agriculture may benefit and improve the wellbeing of those living in cities; where problems relating to mental health and physical wellbeing are increasing despite improvements in living standards and economic prosperity. The issues relating to wellbeing can be broken down into three distinct categories; physical wellbeing, psychological wellbeing, and financial security. The knowledge generated in answering research question three discusses how urban agriculture can benefit urban societies in these three key areas so as to build an understanding of the future socio-economic cohesion of agriculture and urbanity.

Utilising the data collected from research questions one and two, it is possible to calculate that urban agriculture could be responsible for the addition of 170 hectares of green infrastructure to the city of Manchester, which today only has 24.2 hectares of green space. This indicates an increase of 702 percent, which would bring with it many benefits. For example, the city could be up to eight times more effective in cleaning urban air, which increases the ability of the city to sequester carbon, produce oxygen, reduce particulate matter and to varying degrees reduce ozone, nitrogen dioxide, and sulphur dioxide. All of which reduce the probability of urban populations suffering from asthma attacks or developing chronic obstructive pulmonary diseases. The reduction in people with respiratory diseases not only saves money by reducing patient numbers but more importantly, leads towards healthier and happier urban populations. This increase in green infrastructure would also benefit urban populations both psychologically and physiologically.

Natural environments provide restorative services that help the body recover after periods of stress; something that is believed to have followed humans throughout evolution. The restorative qualities of natural environments allow physiological, psychological and social resources to return to their usual levels, which are continually diminished in efforts to meet the demands of everyday life. This natural connection between humans and ecosystems is so strong that it is believed that natural features, even if viewed through a window, allow people the opportunity for 'micro-restorative' experiences in their everyday indoor environment. Although brief, these micro-experiences can mount up to a measurable cumulative benefit. As a

result of building integrated technical food systems, the views from most buildings within any given high-density city would be transformed from those of hard surfaces such as glass, concrete, steel and tarmac to a sea of vegetation spreading across rooftops, spilling down facades and engaging with the public realm at ground-level. Although the majority of this newly created foliage would be inaccessible to most, it would bring with it a multitude of opportunities for micro-restoration throughout the day as well as the development of social engagement opportunities through the introduction of markets, shops and cafes, as well as the development of green corridors and the provision of engaging public spaces.

Through the use of the data collected from research question two - i.e. the economic value of the crops grown - it was also possible to estimate the number of jobs urban agriculture within Manchester could generate. Based on the cost of human capital in large businesses, healthy profit margins for large food retailers, along with the HMRC wage distribution of the UK it was calculated that job creation in Manchester as a direct result of urban agriculture would be 8,385 new jobs. When job creation in the city of Manchester is combined with the total economic value of naturally-lit building integrated technical food systems across the country, the estimated UK job creation would be 128,104. Additionally, urban agriculture can also provide fresh organic food where demand is highest, whilst improving food access for those who are in deprived urban areas. This improved access to fresh organic food could help combat the proliferation of cheap high energy diets which are known to lead to vitamin deficiencies, obesity, diabetes and hypertension, which collectively will help improve the health and wellbeing of urban populations. The key metrics associated with this research question are listed below.

Health and wellbeing key metrics

Increase in green infrastructure in Manchester	170 hectares = 702 %
Job creation in Manchester	8,385
Job creation in the UK	28,104

Conclusions

Unfortunately, the environments provided by the cities of today can negatively affect the wellbeing of urban populations. Air pollution, poor diets, physical inactivity, depression, anxiety and financial insecurity are just some of the primary causal factors leading towards diminished wellbeing within urban centres. However, through the implementation of building integrated technical food systems, a whole host of supporting benefits are created, which can help remedy these issues to varying degrees. These include; an increase in green infrastructure, which would promote both full and micro-restoration of depleted physiological and psychological resources which aids in reducing depression and anxiety; the promotion of exercise through the creation of greener and cleaner urban environments which would have a positive effect on a range of physiological and psychological indicators, including blood pressure, levels of stress hormones, immune system functionality, cognitive functioning, mood and self-esteem; improvements in air quality by decreasing particulate matter, ozone, nitrogen dioxide, and sulphur dioxide, as well as improving the production of oxygen, which would reduce the likelihood of urban populations developing or aggravating respiratory diseases; as well as producing fresh organic foods that could help improve urban diets and creating jobs for many thousands of urban inhabitants; collectively improving wellbeing within cities. As a result of building integrated technical food systems, cities start to become living, breathing ecosystems, where the impenetrable edifices of the past become softer, greener and more inviting; improving the lives of those that work and live within them as well as those who passively engage with them on a day-to-day basis. Ultimately, building integrated technical food systems are capable of producing an estimated 2.74 trillion crops per annum in the UK and creating over 128,000 jobs nationwide, as a byproduct of creating cleaner and more engaging cities.

7.3 - Final thoughts on building integrated technical food systems

In this thesis, the technical challenges that face the integration of technical food systems within existing buildings have been identified, the productivity of vertical and horizontal building integrated technical food systems have been calculated, the proportion of external building surfaces that are capable of supporting crop growth

has been determined, and the potential benefits building integrated technical food systems may provide in the future to urban populations, which have been discussed. This analysis ultimately determined that building integrated technical food systems could provide enough food for 1.5 percent of the UK population, whilst creating over 128,000 jobs nationwide, generating approximately £5.5 trillion per annum, reducing global pollution that is equivalent to taking over 830,000 off UK roads and reducing the demand for cultivated land elsewhere by 1680 square kilometres; equivalent to the size of the Shetland Islands.

Based on the findings in this thesis, it is unlikely that building integrated technical food systems will ever be able to produce enough food to feed the entirety of urban populations or to negate the demand for imported food. However, the arguments for or against the implementation of building integrated technical food systems and urban agriculture as a whole should not be discussed purely in terms of quantity. Although the quantity of food produced by any food system is an important metric, it is only one of three cornerstones that help improve food security; alongside food quality and food access. Urban agriculture and the implementation of building integrated technical food systems offer additional benefits well beyond the production of food. The word 'quality' therefore enters the discussion, which is a key area in which urban agriculture can add value in comparison to other established food systems. For example, building integrated technical food systems can help to reduce obesity and diabetes through improved access to healthy organic foods, they can help in the treatment of those with depression and anxiety in urban centres, as well as improving urban air quality, reducing the development of some non-communicable diseases, reducing the development of asthma and other chronic obstructive pulmonary diseases whilst creating education, training and job opportunities. As a result, it may be more appropriate to refer to building integrated technical food systems and urban agriculture as a whole as a public service due to the role they may play in the future development of the UK; i.e. simultaneously reducing the economic strain on healthcare establishments by improving people's health and wellbeing, producing food for nearly a million people, improving food security, creating jobs, providing training, decreasing the demand for imported foods, mitigating ecological damage, and possibly turning a profit. As a result, individual urban food systems, such as the elevated aquaponic system in Salford, take on the role of community hubs; bringing people together who live close by, as well as

providing access to defensible space; something that can be a rare commodity in high-density low-income areas. Projects like the elevated aquaponic system give people a sense of belonging and contribution to the improvement of their local area, all of which improve the wellbeing of urban populations. The development of the facade-farm envisaged different benefits such as improving the environmental performance of buildings, as well as producing food at the point of sale and improving the environments in which people recover from serious illness, but ultimately strived to improve the lives of those who would engage with such facade-based systems in the future.

Although the benefits of building integrated technical food systems are abundant, the integration of the practice can be complex, especially within or upon existing buildings. The design and construction of the elevated aquaponic system drew attention to the primary technical challenges that face, and will continue to constrain, the integration of technical food systems in the future. For example, the construction of intermediated floor plates within newly built and historic buildings are not designed to carry the heavy loads associated with aquaponic systems. Although this greatly restricts the integration of aquaponic systems within existing buildings due to the requirement for large fish tanks and heavy filtration systems, this thesis has proven that such constraints can be overcome through careful consideration and a close working relationship with structural engineers. The placement of technical food systems within buildings also creates additional issues relating to water ingress, increased humidity and a potential reduction in lettable area throughout cities. As a result, it was recommended in the thesis that such systems should exist solely upon the exterior envelope of buildings - i.e. on rooftops and facades - to reduce the risks posed by water ingress, humidity and to allow interior spaces to remain lettable.

Although the technical difficulties and access to sufficient light levels are key challenges that face the future integration of urban agriculture, it was noted that these are not the only constraints. For example, other factors such as system ownership, access to the right skills and right people, along with the willingness of building owners to want to engage with urban agriculture, are all issues that could potentially hinder the future integration of agriculture within today's cities. Due to this, the integration of urban agriculture should be referred to as both a technical and social challenge, where technology, structural capacity and building location, along

with the different viewpoints of cultures, societies and people, will ultimately determine the future of the practice. That being said, the future looks promising when considering these two entities. For example, the resulting conclusions in this thesis present new information relating to the appropriateness of different food systems in different urban locations and identify that structural limitations can be overcome. In addition to this, the enthusiasm of the volunteers who helped to construct the elevated aquaponic system along with those who attended the two-part aquaponic workshop in Salford is an encouraging first step when considering the role people will play in both supporting and operating future systems.

Food production in the city is in the early stages of a renaissance, and the practices expressed within this thesis prove that building integrated technical food systems are viable both on intermediate floors above ground-level and on rooftops of existing buildings that form the cities of today; as well as identifying the possibility of facade growing in the future. Not only are these systems viable, but they are also capable of growing large quantities of food; removing the need to demolish existing buildings and construct purpose-built edifices, thereby, maximising the untapped potential of cities as they exist today. That being said, even if every city in the UK adopted urban agricultural practices and utilised every external surface that was capable of supporting crop growth, the output of naturally-lit systems would still not be enough to feed even two percent of the UK population, let alone mitigate the shortfall in UK food production; which if nothing else draws attention to the complexities and quantities of food that are associated with feeding even a relatively small country, such as the UK. Although the impact of building integrated technical food systems is expected to be small, its integration can lead to substantial changes when combined with other initiatives such as reducing food waste, minimising meat consumption and reintroducing seasonal diets. Urban agriculture, therefore, sits amongst a range of options that need to be implemented to reduce the impact humans have on the natural environment including the adoption of clean, renewable energy, the reduction of waste streams and the integration of closed loop urbanism, to name a few.

It is envisioned that building integrated technical food systems will ultimately play a pivotal role in people's lives in the future through the reintroduction of ecosystem services in the locations they are most needed - i.e. cities - which will benefit all of those who engage with it, either directly or passively. The overarching conclusion of

this thesis is that existing cities are capable of producing food through the use of building integrated technical food systems, which, in turn, increase resiliency, decrease ecological damage, and improve the health and wellbeing of urban populations. Urban agriculture, and more specifically building integrated technical food systems, may not be the saviour so many thought it would be but these systems offers a collection of public services that no other man-made system can claim to provide, which one day may just save the cities of the future.

8.0

FUTURE

WORK

AND

REFLECTION

8.0 // FUTURE WORK & REFLECTION //

In the previous chapter, the conclusions to the three research questions were given along with some final thoughts on building integrated technical food systems. Although some of the more pressing questions have been addressed within this thesis, such as the challenges that face the integration of technical food systems within existing buildings, the impacts technical food systems may have upon UK food security and the health and wellbeing of urban populations, there are still many more avenues for future research. This supplementary chapter identifies specific long-term research goals that will help improve the understanding of whether urban agriculture can be a driver for serious change and to improve the accuracy of some of the calculations contained within this thesis. The chapter also includes a personal reflection from the author, which gives a brief insight into the delivery of the elevated aquaponic system as well as opinions relating to the differing impacts of urban agriculture and the future of the practice.

8.1 - Future research

Urban agriculture as a movement, as a practice and as a form of agriculture is still very much in its infancy. Due to this, there are many opportunities for future systematic inquiry relating to the integration of food production within today's cities. Specific to this thesis, there are many potential opportunities for further research, to improve the understanding of building integrated technical food systems and the impacts they can have. For example, the building integrated technical food system designed and constructed to enable the writing of this thesis was an aquaponic system. This is primarily because of the benefits aquaponic systems have when compared with hydroponic systems. However, aquaponic systems are more complex, require larger volumes of water to operate and are heavier than hydroponic systems. Therefore, it would be beneficial to undergo the same process relating to the integration of a hydroponic food system within an existing building as a point of comparison. There are many other avenues of systematic inquiry that are related to the progression of the research discussed within this thesis, and these are discussed below. The research goals are broken down into four distinct categories,

which are 'technical food systems', 'light capture analysis', 'biocyclical urbanism' and 'additional challenges of integration'. The future research goals are presented in this way to identify how they fit into the wider discourse of urban food production and how they relate to the progression of the research contained in this thesis.

8.1.1 - Technical food systems

Challenges of hydroponic integration and productivity

The obvious counterpoint to the research contained in this thesis is to address the challenges faced when integrating a hydroponic system within an existing building. Hydroponic systems are lighter, require less water to operate - at least initially - and are comprised of only two elements; i.e. growing equipment and a reservoir. It could be assumed that the integration of such a system might be easier, but without a point of comparison to the elevated aquaponic system, it is difficult to conclude this either way. The integration of a hydroponic system within an existing building would also enable such factors as the initial cost of construction, annual running cost, productivity and inevitable water loss to be compared between real-world hydroponic and aquaponic systems within high-density cities. There are obvious benefits to implementing aquaponic systems when compared with hydroponic systems, but if it is determined that the integration of the latter is quicker and easier, then this may change which system is seen as more appropriate by the wider public with regards to future food production within cities.

The use of multiple internal floors

The design, development and construction of the elevated aquaponic system was constrained by the strength of the building. This led to the placement of fish tanks and the filtration unit above primary steel beams which could carry the additional loads, as well as the use of transfer beams on the roof to help support the polytunnel. Although the structural engineers calculated that the steel structure could support the addition of the elevated aquaponic system when arranged in this way, the fundamental elements of the systems - i.e. the fish tanks and filtration unit - was located on a single floor of the building. If for any reason, it was later decided that the growing area of the roof should be doubled, then additional fish tanks would be

required and the only place these could be placed - at least in the context of Irwell House - would be on the first floor, in the same position as those placed on the second floor. However, the addition of another ten tons of weight to a building in such a state of disrepair could be a step too far. Although it has been recommended that future urban food systems should be restricted to the exterior envelope of existing building, it can again, not be assumed that all future urban food systems will be placed externally. Hence, it is important to understand if existing buildings have a maximum growing capacity based upon their structural integrity. For example, if an existing building required the use of four floors of fish tanks to maximise food production on the roof, but it could only support a maximum load equivalent to the use of two floors, then the building would be half as productive as the roof would suggest. This understanding will be crucial in the future planning of urban food production and could possibly change which sites are considered most applicable if loading capacity is added as a primary driver for integration in addition to light capture, access to points of sale, and willingness of building owners to participate, for example.

Roof only technical food systems

In line with the recommendations made in this thesis - to restrict the placement of technological systems to the envelope of existing buildings - it is important to develop technical food systems that exist solely upon the roof. Much like the facade-farm, which is a self-contained farm that exists as part of the facade of an existing or newly constructed building, a roof-only variant of the elevated aquaponic system needs to be developed along with a roof-only hydroponic system. This would then start to build up a database of different typologies of urban food production, which would have inherent positive and negative aspects, such as a multi-floor aquaponic system, multi-floor hydroponic system, a roof-only aquaponic system and a roof only-hydroponic system, for example. This would then allow different methods of food production within cities to be determined depending on specific factors such as light capture and building strength for example. Although it has been mentioned previously, that the integration of aquaponic systems at roof-level would not be possible, the design and development of the elevated aquaponic system proved that even old and poorly maintained buildings are capable of supporting heavy aquaponic systems if the individual components are positioned correctly. Hence, it

may be possible in the future to locate aquaponic systems on the roof if fish tanks are placed above column locations or the use of transfer floors are employed.

Urban agriculture and human nutrition

An important and interesting question relating to food security and the role of urban agriculture will play in future strategies relating to food security is whether the practice can deliver all the nutrients required by the human body. Typically, aquaponic and hydroponic systems grow lettuces and other leafy vegetables. However, it is unlikely that a diet of lettuce, chard and kale would be sufficient to provide the human body with everything it needs. Hence, it is important to understand what nutrients urban food systems can provide in order to determine which nutrients need to be subsidised. Such an understanding would further improve the conclusions relating to the potential impacts of urban agriculture as a whole.

Certified organic produce from technical food systems

Within the thesis, it was briefly mentioned that aquaponic systems are capable of producing organic foods if the fish are organically bred and organically fed. Although this is the case, there is currently no legislation or official criteria from governing bodies such as the Soil Association, within the UK at least, that enables aquaponic produce to be sold as organic. Hence, even if the produce from an aquaponic farm was technically organic, it could not be sold as organic due to the laws that govern the use of the term. Therefore, it would be beneficial to engage with the governing bodies that determine what is and what is not considered organic to see how organic food production can expand into the realm of technical food systems. The use of technical food systems is only going to increase over the coming years, and on the basis that the Soil Association may not be best equipped to deal with soilless technologies, a new governing body may be required to oversee organic food production within technological food systems in the future.

Facade-farm kinetic prototype

The initial design for the facade-farm prototype was envisioned as a conveyor-belt aquaponic system whereby the plant trays were dipped into the fish tank to both

provide filtration, through the use of media within the trays, to provide nutrients for the plants and to address the issues relating to overshadowing. However, due to financial and time restrictions, it was decided that the facade-farm would have to be a static prototype, whereby a double helix of NFT channels replaced the conveyor system of growing trays. Hence, the next step in the development of the facade-farm is to design and construct a working kinetic prototype that employs the use of the conveyor belt system to grow crops. It is envisioned that a full-scale prototype, such as one for a supermarket, would place the fish tanks at ground level and then the plant trays on conveyor belts would work their way up the front of the facade, to a height of 9 metres, for example, and then return down the rear of the facade to be restocked with fresh water and nutrients.

Challenges of facade-farm integration

Although a working facade-farm prototype was constructed, it was simply a freestanding system that stood within Irwell House. Therefore the design team associated with the delivery of both the elevated aquaponic system and the facade-farm have very little knowledge relating to the technical challenges faced when integrating a facade-farm with an existing building. In addition to this, the data that currently accompanies the facade-farm is simulation driven and not based on a tangible test rig. Therefore, the next stage of the research is to embed a double height facade-farm prototype within an existing building envelope in order to determine the complexities of such a task, which are expected to be even more complex than the integration of the elevated aquaponic system. This will allow first-hand knowledge to be collected, allowing conclusions to be made relating to food production and building energy reduction as a result of the integration. This will include the testing of both internal and external temperature, lux level, relative humidity and CO₂, plus the monitoring of fish tank temperatures and pH levels of the system. All these data streams, when combined, will give a clear indication as to whether such a facade will operate as expected when integrated within an existing building, and will provide an indication to its overall performance if applied to multiple buildings within the same city.

Inclined food systems

As part of the lighting analysis it was identified that over 40 percent of the inner urban area of Manchester was incapable of supporting crop growth at roof-level due to the presence of pitched roofs. Much like the development of the facade-farm, it is also important to develop technical food systems that can operate upon pitched roofs. Currently, it is not known what form this type of system might take, but it can be seen that a conveyor-like system, which was utilised as part of the facade-farm, may be applicable in this context also; with primary access at eaves level so as to reduce the complications brought about by accessing an inclined system. Whatever this system may look like, it is important to consider this context for future food production as it is currently the only surface within existing cities that is not considered capable of growing food.

8.1.2 - Light capture analysis

Detailed light capture analysis of all UK cities

The light capture analysis of the inner urban area of the city of Manchester was thorough but time-consuming. Due to this, it was not possible to replicate this analysis across all sixty-six UK cities. Instead, the data obtained from the detailed analysis of Manchester was used as a point of reference when analysing the other sixty-five cities. The primary metric utilised to calculate the total productivity of UK cities was the number of crops that could be grown per hectare of land that the inner urban area of Manchester sat upon. This process made some rather generous assumptions, that were noted in the analysis, but would ultimately lead towards a generalised estimation of total UK urban food production. Hence, to improve the accuracy of this estimation, it is important to produce a more detailed lighting study for all the UK cities.

Detailed urban analysis to map the most productive areas for different crops

The next level of detail that would be of use when planning the future of urban food production would be to consider the light capture analysis in the context of specific lighting requirements of specific crops. For example, the placement of shade tolerant

crops directly behind tall towers and sun-loving crops in open spaces would allow for more productive, and possibly more economically viable, systems to manifest. When combined with structural capacity and access to points of sale, this additional level of complexity will help better drive the placement of technological food systems in the future.

8.1.3 - Biocyclical urbanism

Addressing the inputs of urban agricultural systems

Within the thesis, it was mentioned briefly that aquaponic systems could utilise some of the waste streams of the city to help produce food and reduce their dependency on the burning of fossil fuels. This would primarily be achieved through the use of vermicomposting systems, which would take waste paper, card and vegetable waste to produce worms and compost. The worms could then be fed to the fish, reducing the need for mass-produced fish food. Although this is a documented opportunity for aquaponic food systems, it is not widely adopted. This could be due to the number of vermicomposting systems that would be required to produce the quantity of food required by the fish within the aquaponic system, or it could be that the breeding of fish on pellet food makes them unlikely to want to eat worms. Regardless of the reasons behind this lack of utilisation, the potential to make use of waste streams of the city is a positive factor of any food system and should be researched further to understand the barriers to this process. In addition to this, the energy requirements of the system also have to be met. Nearly 90 percent of the running costs of the elevated aquaponic system was associated with running the pumps, which moved water between the three main elements of the design; fish tanks, filtration and growing. When combined, these three pumps demanded a similar amount of energy to a household kettle. The only difference between the energy demand of a kettle and that of the elevated aquaponic system, however, is that a kettle is usually only on periodically, whereas the pumps within the elevated aquaponic system needed to move water continuously - 24 hours a day for every day of the year - to ensure the wellbeing of the fish and the productivity of the system. With regards to the design of the elevated aquaponic system, an area was left along the south edge of the roof for the future addition of solar panels, which were estimated to be able to generate the full energy demand of the pumps, at least for some of time dependant on the

weather and time of year. However, without the presence of the solar panels on the roof, it is difficult to determine to what extent the addition of solar panels would reduce the main energy use of the system. In the case of both the major inputs to the system - i.e. fish food and electricity - future research would be needed to better understand how urban technical food systems within high-density cities could one day be carbon neutral, to further reduce the ecological damage of food production.

8.1.4 - Social challenges of integration

Willingness of building owners to partake in urban agriculture

In addition to light capture, building strength and access to points of sale, the willingness of building owners to partake in the practice of urban agriculture will also play a key role in the future integration of urban food systems. If the light capture on a rooftop is good, and the building is of strong construction, and it is also located directly above a point of sale, it may still not be a viable point of food production because the building owner is not willing to allow the production of food within or upon their building. This brings about some interesting questions relating to future food production such as 'who owns the systems?' and 'who owns the buildings?'. For example, the building owner may be willing to rent out their roof to an urban farmer, or their building facades for that matter, for a small fee. Or, they might build the systems themselves and let it out to urban farmers. Although this forms an interesting relationship between building owners and urban farmers, it also identifies building owners as a linchpin of urban food production. If it was the case that not one building owner wanted to have their properties included in a city-wide urban food strategy, the 80 million crops that could be produced in Manchester, for example, would instantaneously drop to zero. It is therefore important to understand, at this early stage, the willingness of building owners to engage in urban agriculture either passively as a landlord, or actively as an owner of urban farms, through the use of interviews and questionnaires.

Do the public care about urban agriculture?

Finally, it is important to understand if the public is passionate about urban farming in any way. It is currently assumed that urban populations are willing to pay a

premium for local organic food that is freshly harvested and grown a roof above the supermarket. However, if this is not the case, it will have huge implications on the business model of urban agriculture in the future. For example, if consumers are only willing to pay £1 per crop - as opposed to the £2 per crop metric utilised within the thesis - then the revenue and job creation associated with urban food production are halved. It is therefore important to understand the public's view on urban agriculture, both as an opportunity to educate urban populations on the wider benefits of the practice, and to see whether the investment that is required to support urban agriculture in the future will be met with economic prosperity or economic loss.

8.2 - Dissemination

A crucial task associated with the completion of any thesis is the dissemination of the data and the knowledge contained within it. With regards to this thesis, the dissemination of the knowledge was accomplished in parallel with the writing of the thesis, rather than after its completion, in order to create academic content as the knowledge was created as well as to ensure the quality of the knowledge contained within the thesis was of a high standing. This strategy resulted in the delivery of three conference papers, of which one was chosen for publication in a journal.

The first paper, entitled 'Facade Farm: Solar Mediation Through Food Production', was written for the Eurosun 2014 conference on solar energy and solar buildings and related to the ongoing development and current findings of the facade farm. This paper was delivered by Andrew Jenkins to delegates of the conference in Aix-les-Bains in France. The second paper entitled 'Planning Urban Food Production into Today's Cities', was written for the Associated of European Schools of Planning (AESOP) conference in 2014 and focused on the light capture analysis of the city of Manchester and how such analysis might form a strategy of urban agricultural integration in the future. This paper was delivery by Professor Greg Keeffe in Leeuwarden, The Netherlands and was considered as one of only seven from the conference to be published in a special issue of the journal 'Future of Food: Journal on Food, Agriculture and Society', which was later published in 2015. The final paper associated with this thesis to date was entitled 'The Integration of Urban

Agriculture and the Socio-economic Landscape of Future Cities'. This was written for the 2017 Planning and Low Energy conference (PLEA) and discussed the potential benefits of urban agriculture relating to the health and wellbeing of urban populations. This paper was delivered by Andrew Jenkins in Edinburgh. The references for the conference papers and journal entry can be found below.

Jenkins, A., Keeffe, G., Hall, T. (2014) Facade Farm: Solar Mediation Through Food Production, *Proceedings of the Eurosun 2014: International Conference on Solar Energy and Buildings* [pdf] Available at
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Jenkins, A., Keeffe, G., Hall, N. (2015). Planning Urban Food Production into Today's Cities. *Future of Food: Journal on Food, Agriculture and Society*, 3(1), pp. 35-47.

Jenkins, A., Keeffe, G. (2017). The integration of Urban Agriculture and the Socio-economic landscape of Future cities. In L. Brotas, S. Roaf, & F. Nicol (Eds.), *Design to Thrive: PLEA Proceedings 2017* (Vol. 3, pp. 4485-4492). Edinburgh: NCEUB.

Although these three papers disseminate a large proportion of the findings contained within this thesis, they do not address the primary aim of the thesis or the conclusions of the thesis. Therefore, it is the intention that upon completion of the thesis a book will be written and published to document the design and development of the elevated aquaponic system and the technical difficulties associated with its integration, as well as discussing the conclusions related to building integrated technical food systems. Through the creation of both a physical book and a downloadable document, it is hoped that the knowledge contained within this thesis can be accessed by a wider audience. It is also seen as beneficial to write two further papers during the delivery of this book to document the productivity of

building integrated technical food systems - discovered as a result of the design and development of the facade farm and elevated aquaponic system - as well as a paper that summarising the knowledge created within the thesis, referencing previous papers to reinforce the findings.

8.3 - Personal reflection

Urban agriculture divides opinion, and those opinions are usually backed up by sensationalist claims that it can feed the world or that it is simply a design trend that won't last. The extensive research contained in this thesis has identified that the impact of urban agriculture, at least within inner urban areas, is relatively small, but nonetheless, significant. What I can say about urban agriculture from first-hand experience is that it has a profound impact on people's lives. Throughout the design and construction of the elevated aquaponic system I had the privilege of working alongside some amazing people from different backgrounds and social standings. I was lucky enough to work with local residents of Black Friars in Salford, who said that the project had given them a new lease of life and I worked alongside stern professionals who lit up when they entered the building. There is something truly special about standing in amongst crops growing on top of a roof that feels right; it feels natural; as if a part of the city was missing before that moment in time. Humans have a strong link with nature, and it is this link that pulls us towards the seas, the forests and the mountains that collectively form our world. Bringing nature into the city in such a way, makes the city feel complete.

The delivery of the elevated aquaponic system was gruelling and backbreaking work, and it was constructed in only a three-month window. It was challenging to design and even harder to build. I can recall one morning when I received a call at six o'clock in the morning saying there had been a huge flood during the night. I helped empty the floor of the building with buckets full of water only later to slip and drive a screwdriver through my hand; later collapsing due to exhaustion. The resulting project, however, was definitely worth the countless fourteen hour days, the sleepless nights and all the pain, because at the end of it all we were all able to stand on the roof of Irwell House, with a beer in hand - the bees buzzing in the hive, the chickens clucking at the far end of the roof, the sound of trickling water through

the NFT channels and the breeze running over the crops within the polytunnel - with the knowledge that we had done something amazing. The project itself was multidisciplinary; requiring many different people from many different backgrounds to complete it. Whether you were a designer, a structural engineer, a project manager, a horticulturist, an aquaculturist, a handyman or handywoman, a local resident, a volunteer, a builder, an academic or just someone who was interested in what we were up to, it felt as though everyone was on the same plane. Everyone worked together to deliver the project, and there was no hierarchy; everyone brought their own unique skills to the table which contributed in some way to the delivery of the system. Urban agriculture, therefore, acts as a social mediator across different disciplines, levels of experience and social standing.

I have been studying architecture for twelve years at the point of writing this thesis, and of those twelve years, I have spent seven years enthralled and excited by closed-loop urbanism. Although I started this process with open eyes, I was hoping that the impact of urban agriculture would be greater. However, I set out with the ambition to calculate the proportional contribution of urban agriculture as objectively as possible, and I was always willing to accept the outcome, even if it did not fit with my 'save the world' agenda. The result of this is that it is now known that urban food production is not the saviour so many thought it might be and we can move forward with the knowledge that urban agriculture sits amongst an extensive list of initiatives that need to occur in order to reduce the strain we put on our natural world through anthropological activities. I have seen and felt the difference urban agriculture can make to cities, even if it was only a small part of it, and I am proud and so very grateful to have been given the opportunity to work on such a thoroughly innovative project. Ultimately, and if nothing else, urban agriculture brings people together, and I truly believe it can make people's lives better as a result because that is exactly the effect it had on me.

Thank you for reading.



Figure 8.1 - Me stood inside the rooftop polytunnel at Irwell House, Salford

9.0

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9.1 - References

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9.3 - Image credits

Unless otherwise stated below, the author is the original creator of the photographs, 2D graphics and 3D graphics seen within this thesis.

Chapter 2.0

Figure 2.1 - Destruction of Amazonian rainforest for cattle pasture

Adriano Gambarini / WWF-Brasil (2011) *Cattle ranching is currently the main driver for large scale forest destruction in the Amazon - but improving management of pastures would benefit Brazil more than just clearing more land* [image online]

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Figure 2.2 - 2008 food riots in South Africa

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Figure 2.3 - Soil-based urban agriculture in Chicago, USA

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Figure 2.5 - Lufa Farms, Montreal

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Figure 2.6 - Urban Organics, Minnesota

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Figure 2.7 - Sky Vegetables, New York

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Figure 2.8 - Farmscraper towers by Vincent Callebaut Architects

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Figure 2.9 - The High Line by Diller, Socifio and Renfro in New York, USA

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Figure 2.10 - Bosco Verticale towers by Boeri Studio in Milan, Italy

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Chapter 4.0

Figure 4.2 - Alice Street Community Gardens - Boston, USA

David Sinclair (2007) Alice Street Community Gardens: a nice little co-op garden [image online] Available at: <<https://www.flickr.com/photos/dejus/559361511>> [Accessed 8th July 2017]

Figure 4.3 - Middlesbrough Urban Farming Project - Middlesbrough, UK

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Figure 4.4 - Southeast False Creek Temporary Community Garden - Vancouver, Canada

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Figure 4.5 - Gary Comer Youth Centre - Chicago, USA

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Figure 4.8 - Mizuna lettuce growing aboard the International Space Station

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Figure 4.12 - Typical layout of an NFT system (Resh, 2013)

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Figure 4.13 - Modern NFT system

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Figure 4.14 - Vertical NFT system at Epcot, Florida

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Figure 4.15 - Cascade NFT growing system

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Figure 4.17 - Example of a water culture raceway growing system

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Figure 4.18 - Example of a small-scale water culture system

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Figure 4.20 - Vertical aeroponic growing system

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Figure 4.21 - Media bed growing system

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Figure 4.22 - Ebb and flow system

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Figure 4.23 - Gravity based trickle system

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Figure 4.25 - Exterior of The Plant, Chicago

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Figure 4.27 - Exterior of Urban Organics, Minnesota

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Figure 4.28 - Fish tanks at Urban Organics, Minnesota

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Figure 4.29 - Water culture system at Urban Organics, Minnesota

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Figure 4.30 - Exterior of FARM:shop, UK

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Figure 4.31 - Interior of FARM:shop, UK

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Figure 4.32 - Water culture system at Growing Underground, UK

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Figure 4.33 - Salad crops at Growing Underground, UK

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Figure 4.34 - Exterior of Freight Farms, UK

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Figure 4.35 - Interior of Freight Farms, UK

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Figure 4.36 - Water culture system at Sanriku Fukko Plant Factory, Japan

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Figure 4.37 - Worker with produce at Sanriku Fukko Plant Factory, Japan

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Figure 4.38 - Rooftop greenhouses at Sky Vegetables, New York

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Figure 4.39 - Interior of rooftop greenhouses at Sky Vegetables, New York

Sky Vegetables (n.d.) [image online] Available at:
<<http://www.skyvegetables.com/bio-1/>> [Accessed 18th July 2017]

Figure 4.40 - Rooftop greenhouses at Lufa Farms, Montreal

Lufa Farms (2013) *Aerial view of Lufa Farms, the world's first commercial rooftop greenhouses. Montreal neighborhood of Ahuntsic-Cartierville* [image online]

Available at:

<https://commons.wikimedia.org/wiki/File:Lufa_Farms_Aerial_view_of_Montreal_rooftop_greenhouse3.jpg> [Accessed 19th July 2017]

Figure 4.41 - Interior of rooftop greenhouses at Lufa Farms, Montreal

Inhabitat (2012) *Lufa Farms veg production* [image online] Available at:

<<http://inhabitat.com/lufa-farms-brings-large-scale-rooftop-farming-to-montreal/>> [Accessed 19th July 2017]

Figure 4.42 - Vertical growing at Bell Book & Candle Restaurant, New York

Ibiza Farm (n.d.) *Bell Book and Candle Restaurant, New York City* [image online]

Available at: <<http://www.ibiza.farm/aeroponic-farms/>> [Accessed 19th July 2017]

Figure 4.43 - Strawberry production at Bell Book & Candle Restaurant, New York

(Credit: Future Growing (2013) *Summer 2013: Fresh strawberries are used to garnish desserts and Chef John Mooney's summer garden salad* [image online]

Available at: <<https://futuregrowing.wordpress.com/2013/07/30/bellbookandcandle/>> [Accessed 19th July 2017]

Chapter 5.0

Figure 5.17 - Surface cracking to the screed of the second floor slab

Mark Brooker (2012) Photo 7 - *Crack In Second Floor Slab* [photograph] (Taken from Structural Investigation Report On Building At Irwell House East Philip Street Salford - Revision A (See Appendix B)

Figure 5.18 - Failed concrete lintel due to water ingress

Mark Brooker (2012) *Photo 29 - Water Damaged Lintel* [photograph] (Taken from Structural Investigation Report On Building At Irwell House East Philip Street Salford - Revision A (See Appendix B))

Figure 5.20 - Initial large-scale aquaponic system design

Andrew Jenkins and Natalie Hall (2012) *Initial large-scale aquaponic system design* [3D graphic] (taken from Andrew Jenkins' archive)

Figure 5.32 - Proposed beam to column stiffening detail

Building Design Partnership (2013) *Proposed Beam to Column Stiffening* [Sketch] (Taken from Structural Calculations Irwell House March 2013 (See Appendix G))

Figure 5.41 - Visualisation of the final design showing polytunnel on the roof, fish tanks, filtration unit and window systems on the second floor along with lecture space on the first floor

Morgan Grennan (2013) *Biospheric project visualisation* [3D Graphic] (taken from Morgan Grennan's archive)

Figure 5.56 - Three-dimensional model and virtual test rig of supermarket facade-farm

BDP (2013) *Three-dimensional model and virtual test rig of supermarket facade-farm* [3D Graphic] (taken from BDP Facade-farm climatic analysis (see Appendix Q))

Figure 5.57 - A comparison of single-skin and double-skinned facades relating to the energy demands of adjacent spaces for heating and cooling in winter and summer

BDP (2013) *A comparison of single-skin and double-skinned facades relating to the energy demands of adjacent spaces for heating and cooling in winter and summer*

[2D Graphic] (taken from BDP Facade-farm climatic analysis (see Appendix Q))

Figure 5.58 - Energy received by a south facing facade-farm with a requirement of 1 MJ/m²/Day to initialise plant growth

BDP (2013) *Energy received by a south facing facade-farm with a requirement of 1 MJ/m²/Day to initialise plant growth* [2D Graphic] (taken from BDP Facade-farm climatic analysis (see Appendix Q))

Figure 5.59 - Light energy received on the growing plane within the facade farm facing different orientations during the summer solstice in the UK

BDP (2013) *Light energy received on the growing plane within the facade farm facing different orientations during the summer solstice in the UK* [2D Graphic] (taken from BDP Facade-farm climatic analysis (see Appendix Q))

Chapter 6.0

Figure 6.1 - Inner urban area of Manchester

Google Earth (2017) [photograph] 53°28'50.59"N, 2°14'32.10"

Figure 6.25 - Example of inner urban area analysis - Newport 19 Hectares

Google Earth (2016) [photograph] 51°35'13.75"N, 2°59'41.78"

10.0

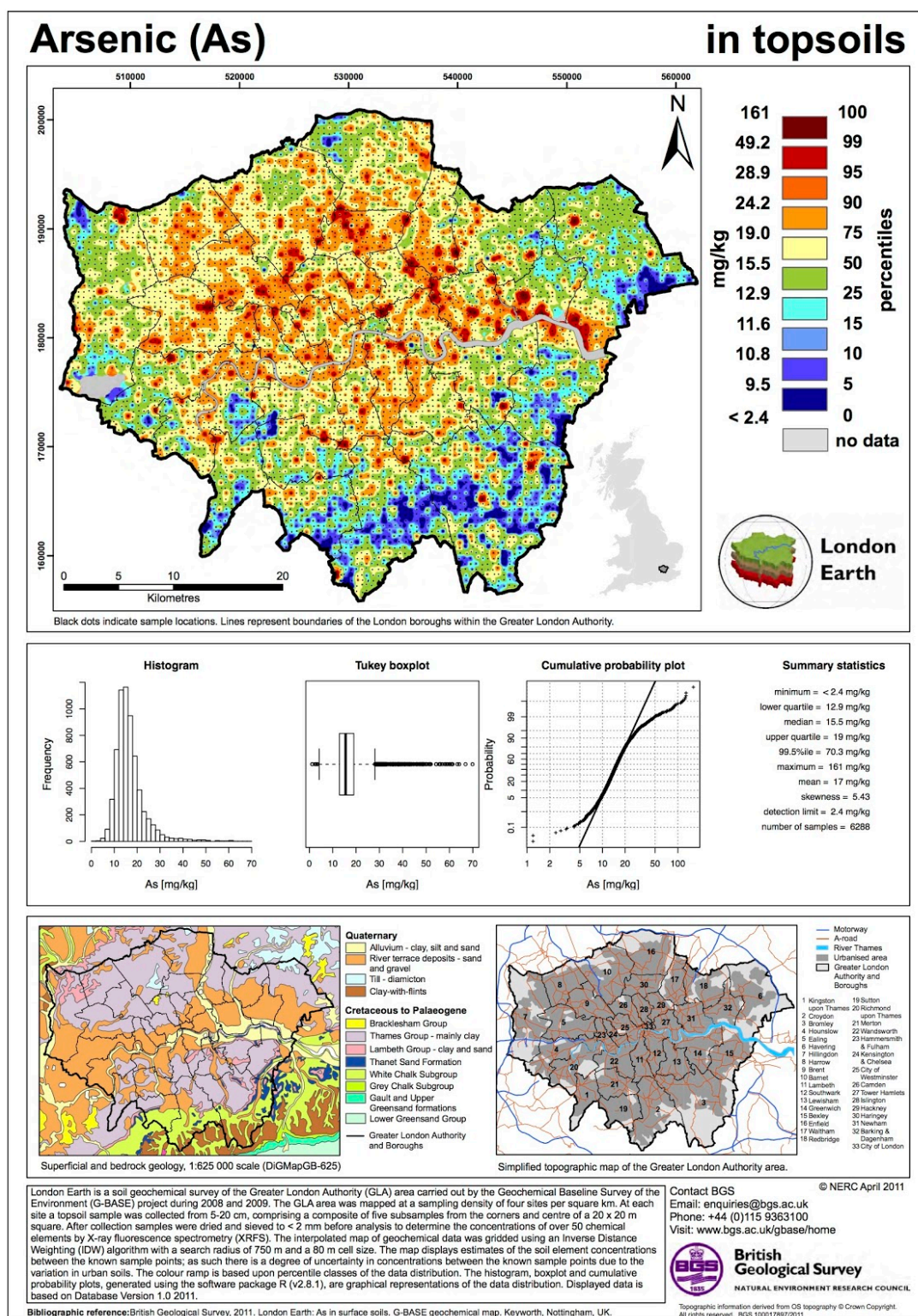
APPENDICES

APPENDIX

A

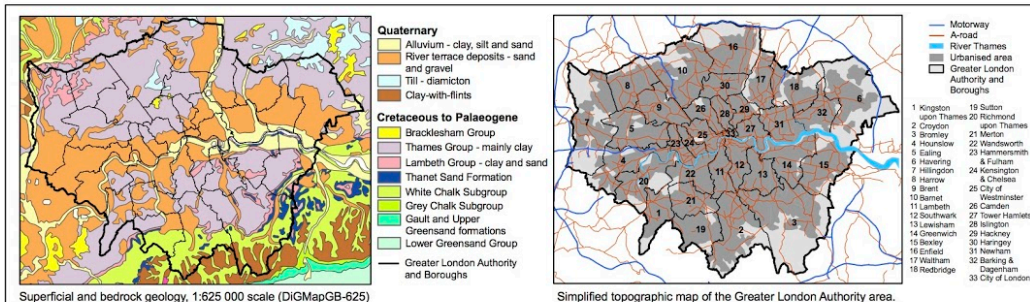
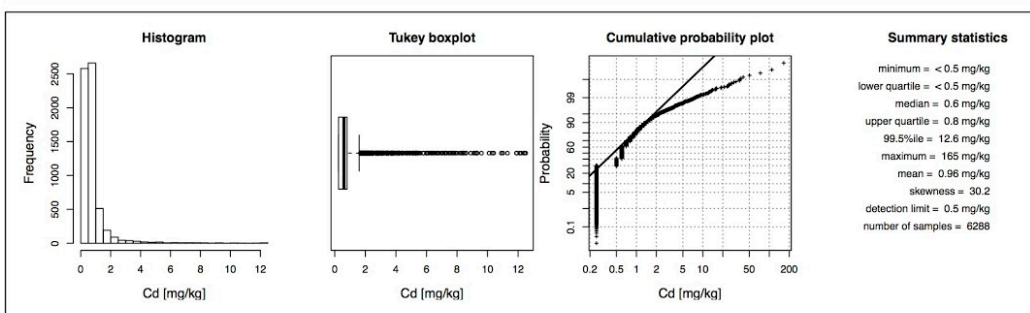
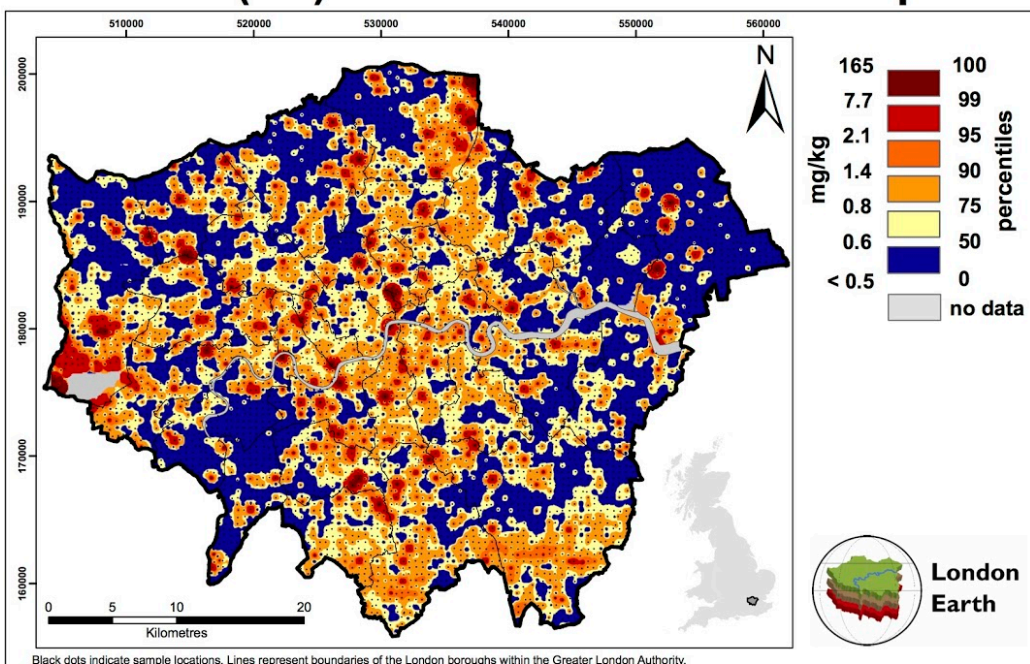
APPENDIX A

London Earth - Data Sheets



Cadmium (Cd)

in topsoils



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Bibliographic reference: British Geological Survey, 2011. London Earth: Cd in surface soils. G-BASE geochemical map. Keyworth, Nottingham, UK.

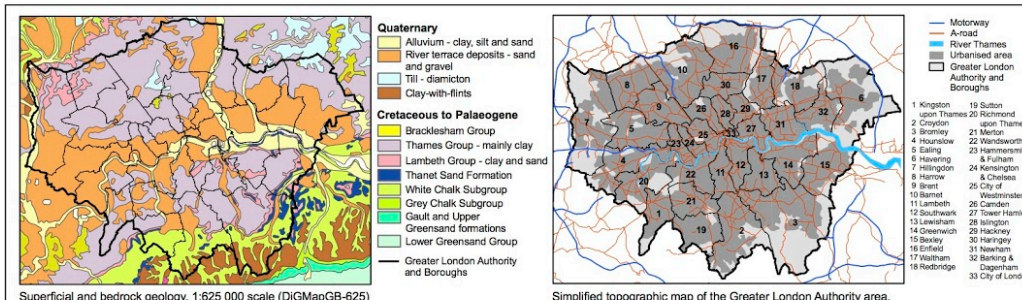
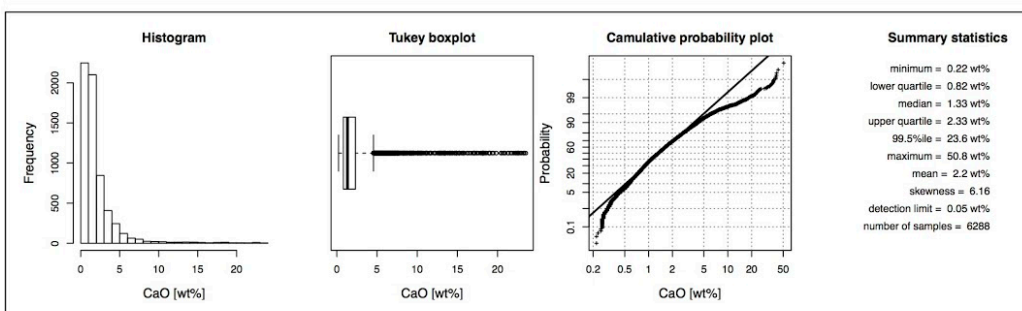
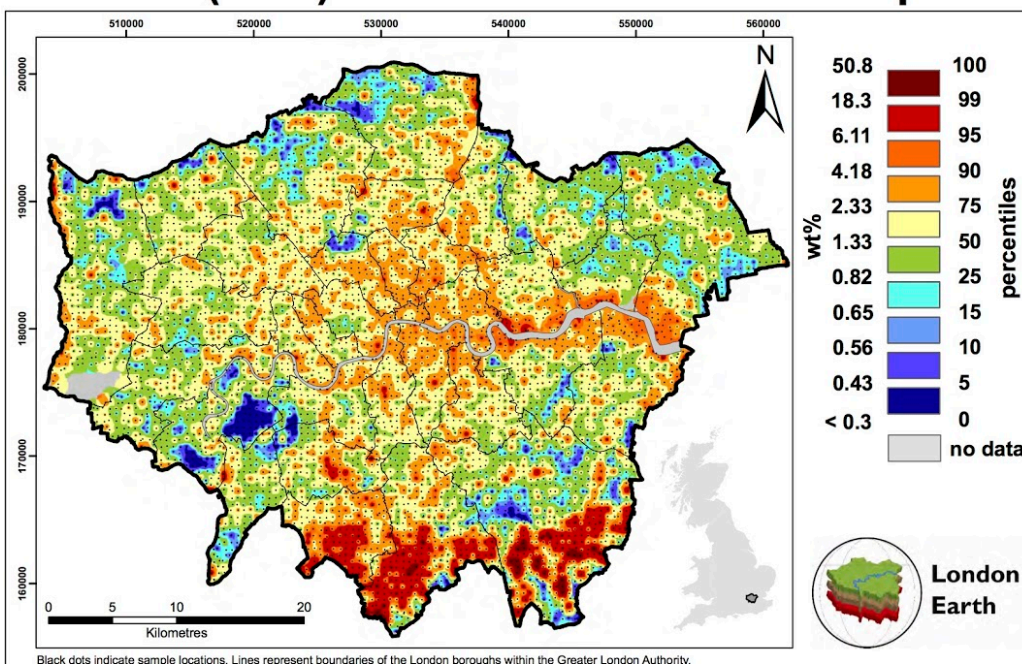
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Calcium (CaO)

in topsoils



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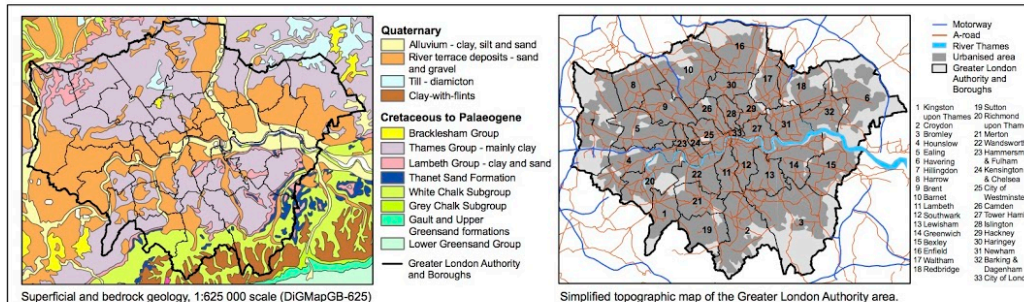
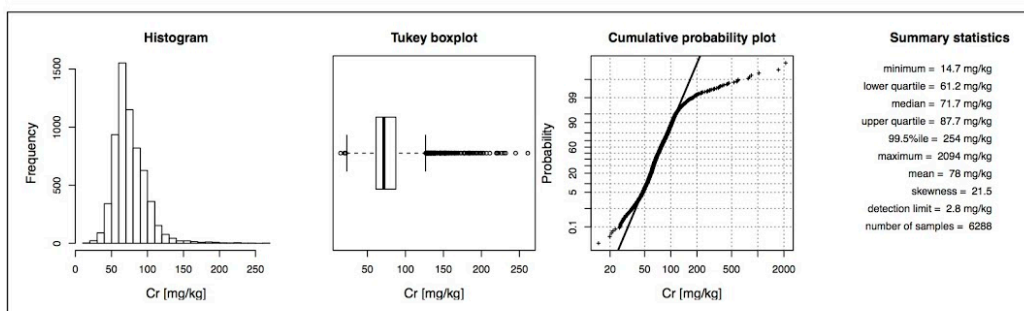
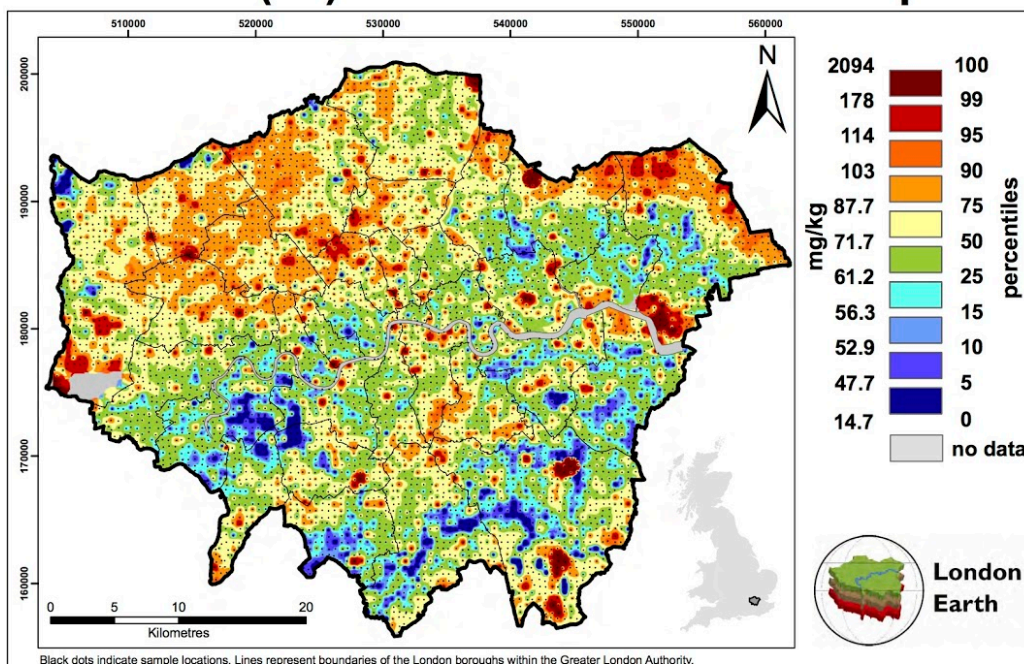
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Chromium (Cr)

in topsoils



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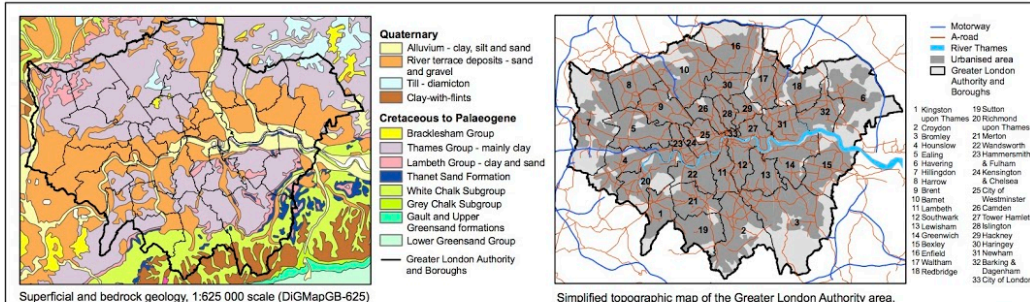
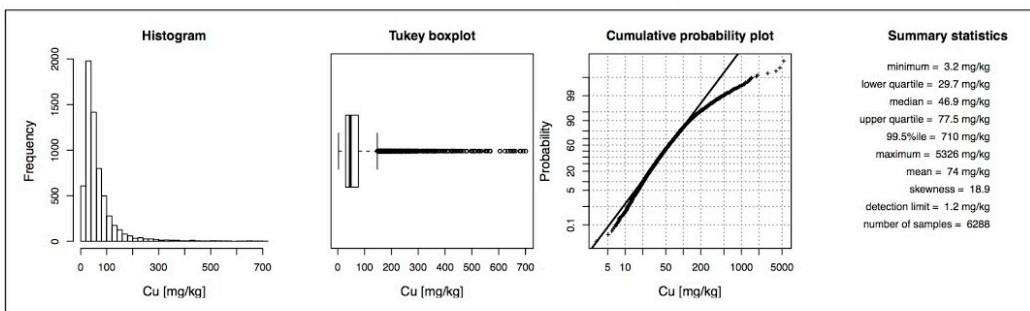
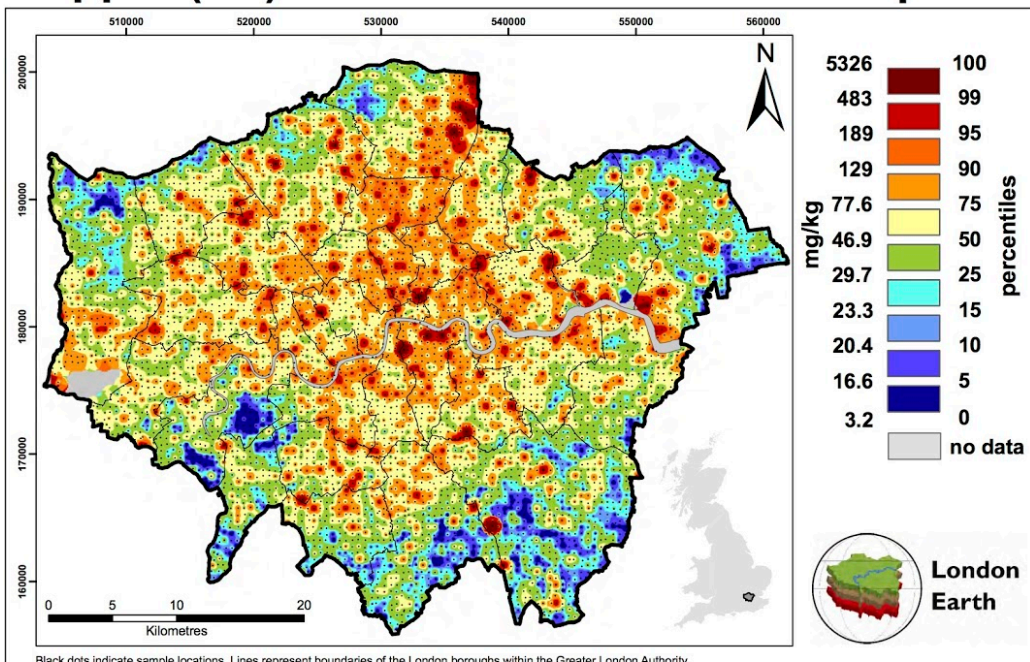
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Copper (Cu)

in topsoils



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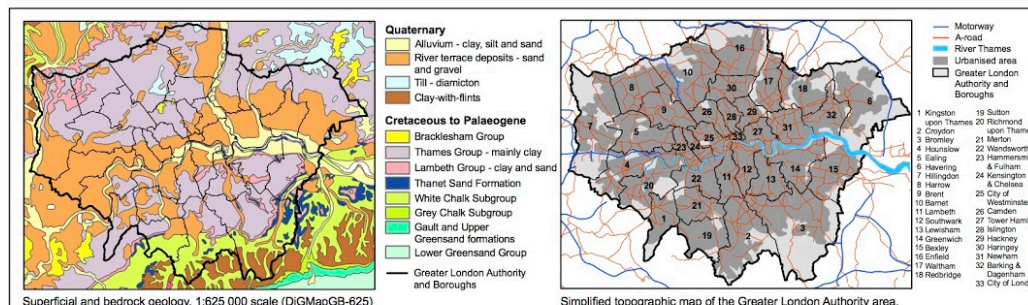
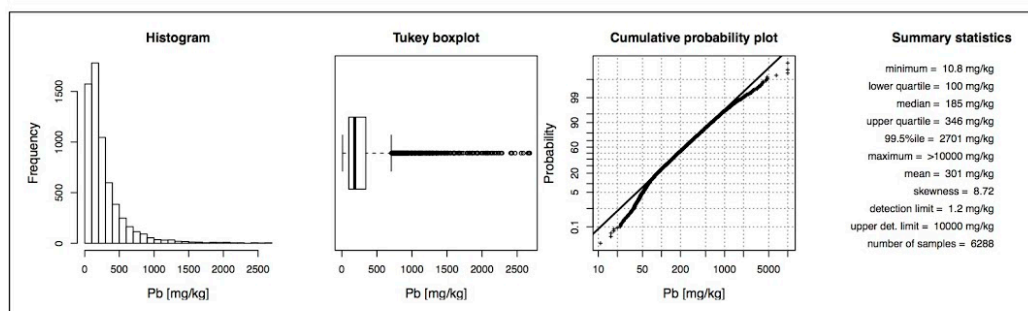
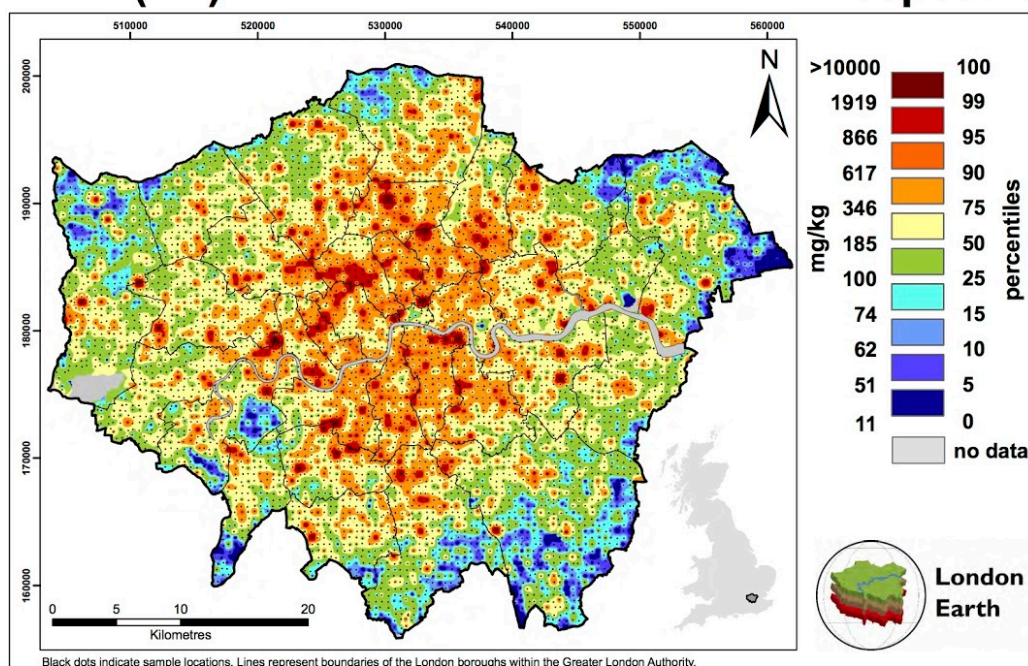


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Lead (Pb)

in topsoils



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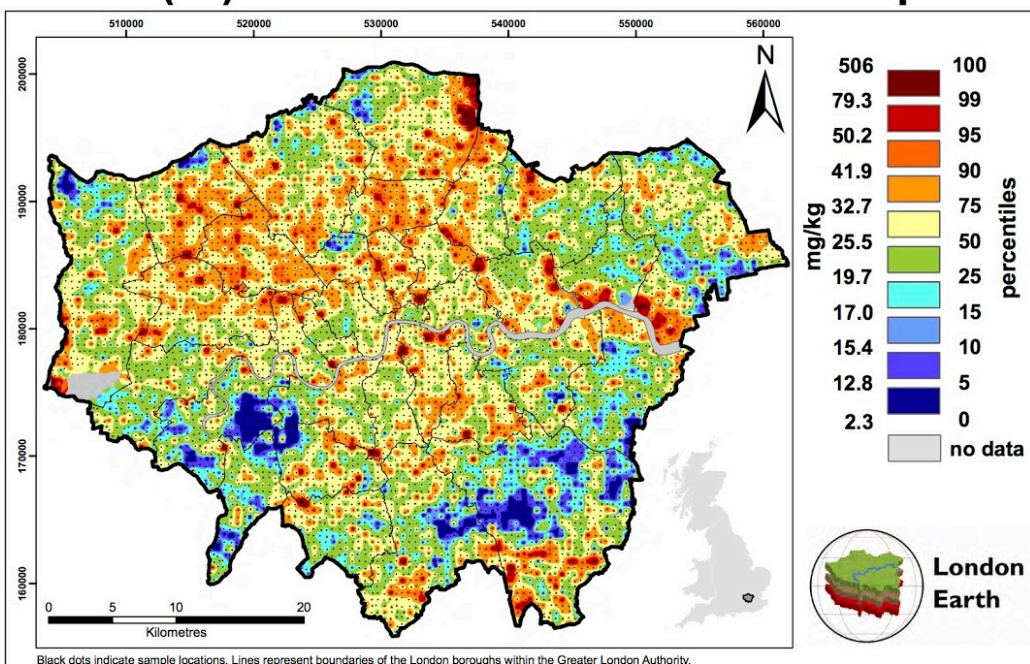
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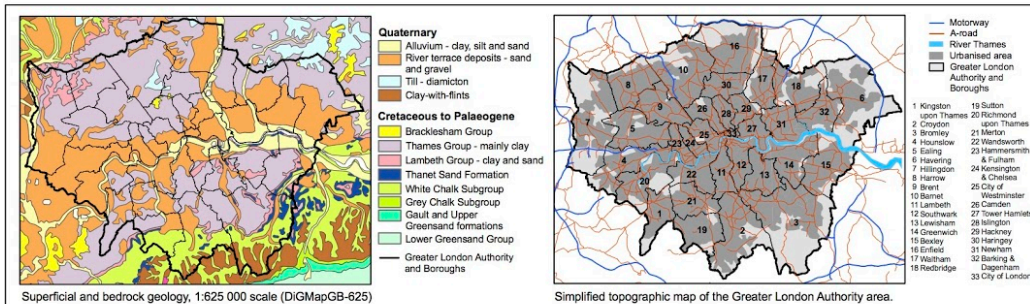
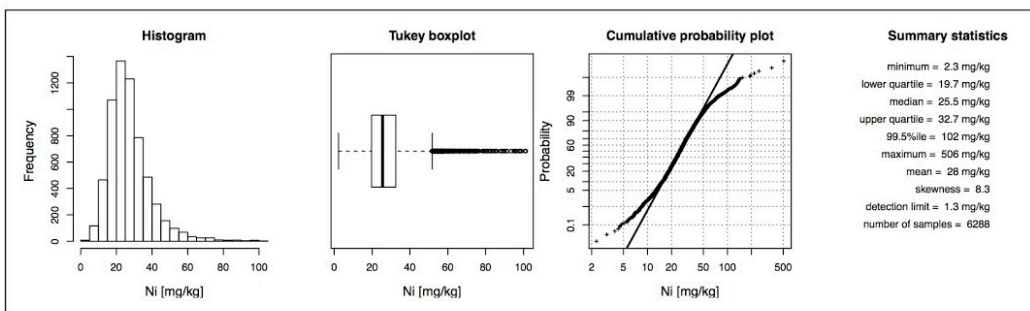
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Nickel (Ni)

in topsoils



Black dots indicate sample locations. Lines represent boundaries of the London boroughs within the Greater London Authority.



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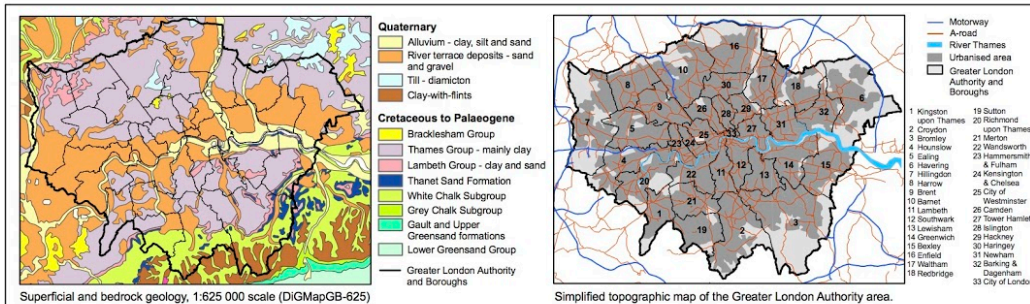
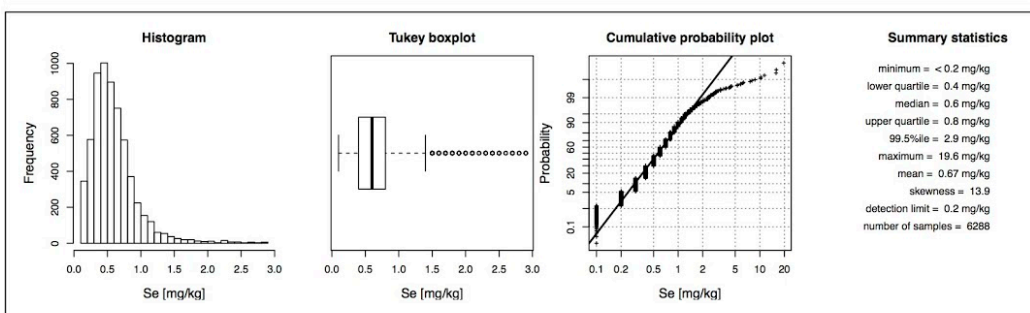
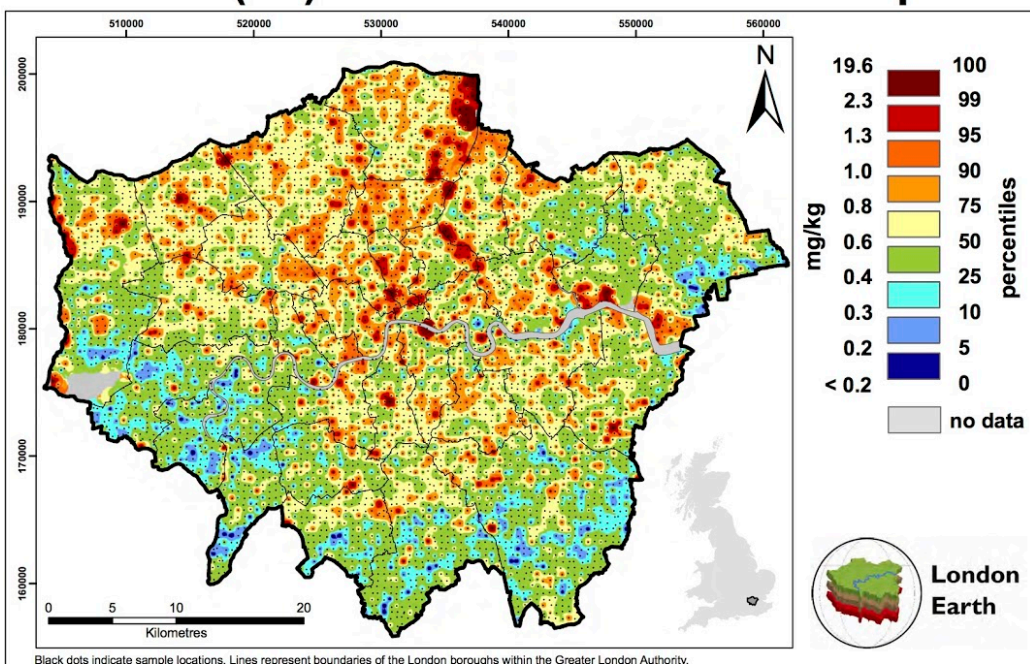
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Selenium (Se)

in topsoils



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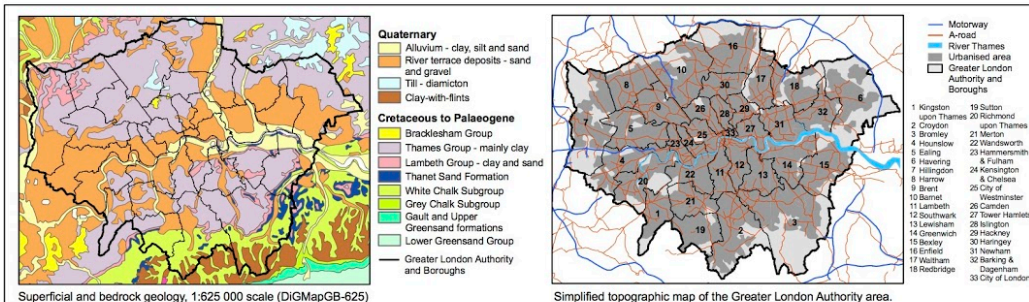
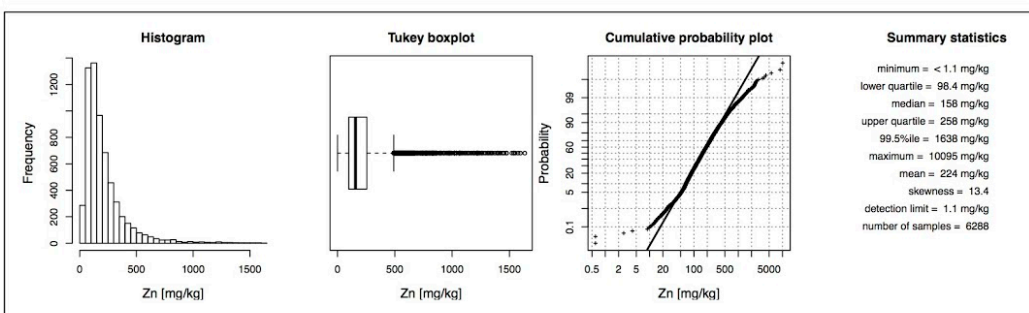
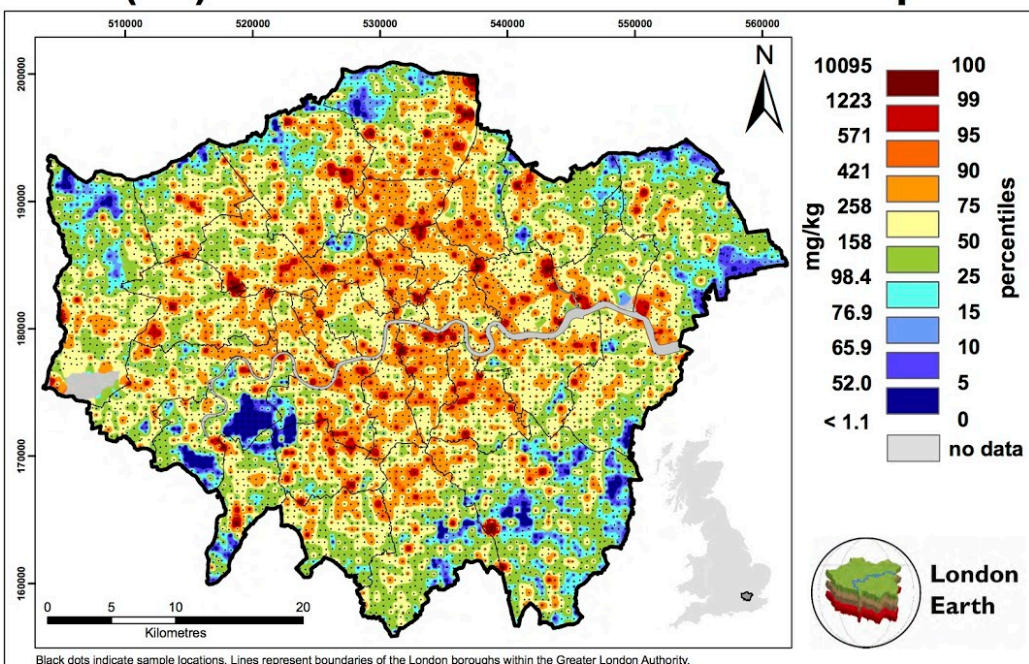
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Zinc (Zn)

in topsoils



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APPENDIX

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APPENDIX B

Structural Report - MB Structures April 2012

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	DESIGNER MB	DATE Apr '12	CHECKED
	DRAWING REF.		
CONTRACT IRWELL HOUSE SURVEY	PART OF STRUCTURE		
<div style="text-align: center;"><p><u>STRUCTURAL INVESTIGATION REPORT</u> <u>ON BUILDING</u></p><p><u>AT</u></p><p><u>IRWELL HOUSE</u> <u>EAST PHILIP STREET</u> <u>SALFORD</u> <u>M3 7LE</u></p><p>REVISION A - Additional calculations produced to confirm loadings from tanks in proposed layout,</p><p>Prepared by - Mark Brooker C Eng MStructE</p><p>Date - April 2012</p></div>			

STRUCTURAL INVESTIGATION REPORT
ON IRWELL HOUSE, EAST PHILIP STREET, SALFORD

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IRWELL HOUSE STRUCTURAL INSPECTION

1.0 INTRODUCTION

MB Structures Ltd were employed by Manchester International Festival, to carry out a structural inspection of Irwell House, East Philip Street, Salford.

The purpose of the survey was to investigate and comment on the structural condition of the building and provide guidance with regards the load capacity of each floor.

The inspection was carried out by Mark Brooker of MB Structures Ltd on 2nd April 2012.

Additional structural calculations were carried out following the setting out of tanks on the second floor. This information can be found within Appendix E.

2.0 BUILDING PREVIOUS USAGE

It was not possible to access the ground floor and the second floor of the building has been renovated. As such it was not possible to determine what these floors have been used for previously.

An investigation of the first floor however showed signs of machinery being fixed to the floor and there was documentation signifying that it had previously been used by 'Park Engraving Co Ltd'.

3.0 BUILDING PROPOSED USAGE

It is the intention that the building be used for festivals and workshops to experiment with the growing of different plants under different conditions.

4.0 BUILDING DESCRIPTION

4.1 Building Construction

The building comprises an envelope of brickwork construction. It could not be determined whether the walls were of solid or cavity construction.

Windows within the perimeter walls are of uPVC or timber construction with concrete lintel and masonry sill.

Internally, the first and second floor and the roof are of beam and block construction with scread finish, spanning onto steel beams which are supported on the perimeter walls and internal steel columns.

The roof of the building is flat with a weather resisting membrane to provide water tightness.

4.2 Ground Floor

It was not possible to inspect the ground floor of the building as this is occupied by an un-related tenant.

4.3 First Floor

The first floor is of beam and block construction with several timber partitions dividing up the floor area. The downstand of the second floor support beams above were seen to have asbestos cladding, as were the support columns. As such it was not possible to determine existing steelwork sizes.

It is the Clients intention to use this floor in the future and as such the asbestos cladding will be removed as this floor is regenerated. Steelwork sizes will be determined following the removal of this cladding.

4.4 Second Floor

The second floor is of beam and block construction supported on steelwork beams and columns below.

Work has been carried out to the second floor of the building to allow for the first phase of the agricultural works.

This work includes the removal of all asbestos from beams and their re-cladding with fire boarding. All timber partitions have been removed and the floor has been painted.

4.5 Roof

The roof is of beam and block construction supported on steelwork beams and columns below.

The roof has a watertight membrane finish.

There is a small height masonry parapet to the perimeter of the roof.

Handrailing has been installed to the elevation adjacent the roof access hatch to provide edge protection.

5.0 STRUCTURAL INSPECTION

The structural inspection of the building took the form of a visual inspection of all areas to identify areas of structural damage. In certain cases breaking out work was carried out to determine the make up of structure.

Photographs taken during the inspection are included within Appendix A.

5.1 Ground Floor

It was not possible to gain access to the ground floor and as such it is not possible to comment on the condition of any of the structural elements to this floor.

5.2 First Floor

Due to the amount of timber partitioning and debris to this floor it was not possible to carry out a full structural inspection of this floor.

The size of second floor support beams could not be determined due to the asbestos cladding around them.

The limited survey that could be carried out showed no signs of structural movement within the side walls / columns and there did not appear to be any cracking to the floor slab.

The downstand to the second floor support beams measured as per the roof support beam downstands. As such it can be assumed that the second floor beams are of the same size as the roof support beams.

5.3 Second Floor

An inspection of the second floor showed cracking to the floor surface in several areas. These cracks in most cases were present along main grid lines above supporting beams.

An intrusive survey was carried out within the area of the crack to determine the cause of the crack and determine the make up of the floor slab.

The slab was found to be made up from 150mm beams spanning between steel beams, with block infills supporting a 75mm thick screed and 25mm wearing screed.

When breaking out it could be seen that the cracking was contained to the top 25mm wearing screed, with no cracking to the 75mm screed below.

It can be assumed that the cracking to the screed is due to slight movements within the slab from beams flexure or expansion / contraction, and the fact that there is no anti-crack reinforcement in either screed.

It is considered that the cracking within the screed has no detrimental effect on the structural strength or stability of the floor.

5.4 **Roof**

An inspection of the roof showed the water proofing to be in a good state of repair and the lack water marks to the second floor ceiling suggests there is minimul / no water ingress.

Removal of fire cladding around steelwork in a selective area showed the 406x140UB secondary beams supported on 457x152UB main beams.

A general arrangement drawing of the roof support steelwork can be found within Appendix B. It is assumed that the steelwork arrangement and sizes are similar to the underside of the second and first floors.

A seating cleat connection was used to connect beams to the 254x146UB columns, with masonry piers being used to support beams on the perimeter walls.

The limited amount of exposed steelwork that was observed appeared to be in a good condition and there is no reason to believe that any of the building support steelwork is in a poor condition.

5.5 Elevations

The masonry to all elevations appeared to be in an acceptable condition with no signs of cracking.

All concrete window lintels to ground and first floors appear to be in a good condition with no signs of distress.

All concrete lintels to the second floor are in a poor condition and in most cases concrete has spalled away to the internal and external face exposing the reinforcement within. It is assumed that this has been caused by water running off the roof and down the outside face of the building, prior to the masonry parapet being constructed / water proofed.

It is considered that these lintels are in a poor structural condition and that they should be replaced by a reputable Contractor with Naylor R6 (or similar following determination of exact wall thickness).

It can be said that there has been little movement of the masonry to the elevations and as such they are considered to be structurally stable.

5.6 Foundations

It was not possible to determine the size or depth of the building foundations, however it can be assume that they are adequate due to the lack of movement of walls or steelwork.

6.0 STRUCTURAL ASSESSMENT

Following the intrusive survey of certain areas it was possible to determine the floor make up and the size of steelwork support for the roof. This is assumed to be similar for the second and first floor supports.

6.1 Beam and block floor

The beams were found to be 150mm deep x 40mm wide with a 20mm wide step to support the blocks. Beams were located at 220mm centres.

Unfortunately the age and manufacturer of the beams could not be determined.

For analysis purposes information for beams presently produced by Charcon Flooring, with a similar cross section, will be used to determine the capacity of the floor.

Design calculations to determine the floor capacity can be found within Appendix C.

The design calculations showed the floor to be capable of supporting an imposed blanket load of 3.5KN/m^2 . This equates to 200mm height of earth or 350mm height of water spread over the whole area.

The allowable imposed load of 3.5KN/m^2 does not conform with the required loading of 4.0KN/m^2 as required in BS6399-1:1996 for 'Museum floors and art galleries for exhibitions. It can however be assumed that there will be no overcrowding and as such the load will never reach this value.

It is recommended that access be restricted should overcrowding become an issue.

6.2 Support steelwork

Following the determination of the allowable loading of the floors and roof, design calculations were carried out to confirm the ability of the support steelwork to support these loads.

Design calculations for the analysis of the support steelwork can be found within Appendix D.

Design calculations show the existing floor support beams to be adequate to support the loads applied.

Unfortunately due to the lack of access to the ground floor it was not possible to determine the size of the columns at this level.

As such a design check on the columns could not be carried out.

It can be assumed that the columns are adequate to support the loads applied by the fact that they are cast in concrete and as such are acting compositely.

7.0 CONCLUSIONS

The structural inspection of the building showed no major structural defects, with the exception of the concrete lintels above the second floor windows which should be replaced.

Calculations showed the floor slabs to be capable of supporting an imposed load of 3.5KN/m^2 , with the support beams being able to carry this loading.

MB Structures Ltd are to be contacted should larger loads than those stated in this report be required to be supported on the floors to allow further analysis to be carried out.

APPENDIX A

INSPECTION PHOTOGRAPHS



PHOTO 1
FIRST FLOOR



PHOTO 2
FIRST FLOOR



PHOTO 3
FIRST FLOOR



PHOTO 4
FIRST FLOOR



PHOTO 5
SECOND FLOOR



PHOTO 6
SECOND FLOOR



PHOTO 7
CRACK IN SECOND FLOOR SLAB



PHOTO 8
CRACK IN SECOND FLOOR SLAB



PHOTO 9
CRACK IN 25mm SCREED ONLY



PHOTO 10
CRACK IN 25mm SCREED ONLY



PHOTO 11
SECTION THROUGH SLAB



PHOTO 12
CRACK IN 25mm SCREED ONLY



PHOTO 13
ROOF SUPPORT STEELWORK



PHOTO 14
ROOF SUPPORT STEELWORK



PHOTO 15
ROOF



PHOTO 16
ROOF



PHOTO 17
ROOF



PHOTO 18
ROOF



PHOTO 19
FRONT ELEVATION



PHOTO 20
FRONT / END ELEVATION



PHOTO 21
FRONT ELEVATION



PHOTO 22
REAR ELEVATION



PHOTO 23
WATER DAMAGED LINTEL



PHOTO 24
WATER DAMAGED LINTELS



PHOTO 25
WATER DAMAGED LINTEL



PHOTO 26
WATER DAMAGED LINTEL



PHOTO 27
WATER DAMAGED LINTEL



PHOTO 28
WATER DAMAGED LINTEL



PHOTO 29
WATER DAMAGED LINTEL

APPENDIX B

FLOOR SUPPORT STEELWORK ARRANGEMENT



**TYPICAL FLOOR PLAN
(SHOWING STEELWORK)**

APPENDIX C

BEAM & BLOCK FLOOR ASSESSMENT

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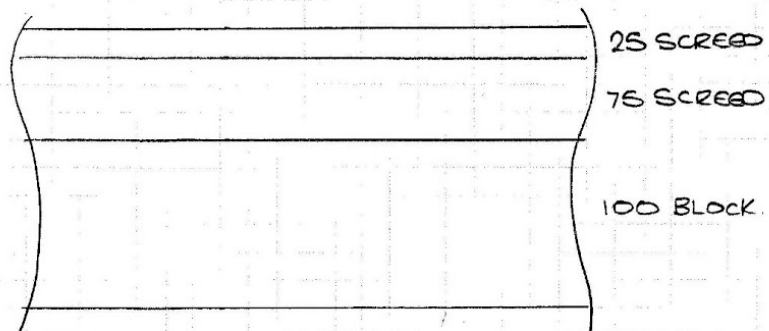
CONTRACT

IRWELL HOUSE

PART OF STRUCTURE

FLOOR LOADING

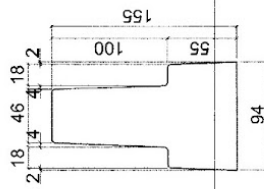
DEAD.



$$\begin{aligned} \text{DEAD LOAD - } 25 \text{ SCREED} &= (0.025 \times 24) = 0.6 \text{ kN/m}^2 \\ 75 \text{ SCREED} &= (0.075 \times 24) = 1.8 \text{ kN/m}^2 \\ 100 \text{ BLOCK} &= (0.1 \times 6.5) = 0.7 \text{ kN/m}^2 \\ \text{TOTAL DEAD} &= \underline{3.1 \text{ kN/m}^2} \end{aligned}$$

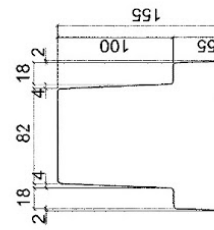
Prestressed concrete floor beams

CR94 beam



Span load tables CR94 typical application	Infill block density kg/m ³	65mm screed finish 1.5kN/m ²			Dry finishes 0.2kN/m ²		
		Superimposed loadings kN/m ²			Superimposed loadings kN/m ²		
		1.5	2.0	2.5	1.5	2.0	2.5
Case S494	650	4.20	3.95	3.55	5.14	4.71	4.38
	1350	3.91	3.52	3.18	4.63	4.31	4.05
Case S382	650	4.72	4.46	4.23	5.50	5.27	4.91
	1350	4.41	4.19	4.00	5.20	4.86	4.57
Case S269	650	5.49	5.18	4.94	5.50	5.50	5.50
	1350	5.17	4.92	4.71	5.50	5.50	5.34

CR130 beam



Span load tables C130 typical application	Infill block density kg/m ³	65mm screed finish 1.5kN/m ²			Dry finishes 0.2kN/m ²		
		Superimposed loadings kN/m ²			Superimposed loadings kN/m ²		
		1.5	2.0	2.5	1.5	2.0	2.5
Case S530	650	5.00	4.72	4.49	6.00	5.56	5.19
	1350	4.69	4.46	4.26	5.50	5.14	4.84
Case S418	650	5.54	5.24	4.99	6.00	6.00	5.74
	1350	5.22	4.97	4.75	6.00	5.71	5.39

CHARCON FLOORING LITERATURE

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	DESIGNER MB	DATE Apr '12	CHECKED
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CONTRACT IRWELL HOUSE		PART OF STRUCTURE	

CHARCON FLOORING.

IL = 1.5 kN/m²

DL = (1.5 + (0.1 x 6 S)) = 2.2 kN/m
 IL = 1.5 kN/m
 TOTAL = 3.7 kN/m

5.49

$M = [(1.4 \times 2.2) + (1.6 \times 1.5)] \times \frac{5.49^2}{8} = 21 \text{ kNm}$

IL = 2.0 kN/m²

DL = 2.2 kN/m
 IL = 2.0 kN/m
 TOTAL 4.2 kN/m

5.18

$M = [(1.4 \times 2.2) + (1.6 \times 2.0)] \times \frac{5.18^2}{8} = 21 \text{ kNm}$

IL = 2.5 kN/m²

DL = 2.2 kN/m
 IL = 2.5 kN/m
 TOTAL 4.7 kN/m

4.94

$M = [(1.4 \times 2.2) + (1.6 \times 2.5)] \times \frac{4.94^2}{8} = 21 \text{ kNm}$

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DETERMINE ALLOWABLE IMPOSED LOAD FOR BEAM.
& BLOCK FLOOR WITH 4.0m SPAN.

DL = 3.1 kN/m
IL = ?

$$M = [(1.4 \times 3.1) + (1.6 \times X)] \times \frac{4.0^2}{8} = 21 \text{ kNm}$$

$$(4.3 + 1.6X) \times 2.0 = 21 \text{ kNm}$$

IMPOSED LOAD = 3.9 kN/m²

DUE TO THE LACK OF INFORMATION ON THE EXISTING BEAMS
 REDUCE LOAD BY 15% TO ALLOW FOR NEWER
 CONSTRUCTION MATERIALS.

ALLOWABLE IMPOSED LOAD = (3.9 \times 0.85) = 3.5 kN/m²
 (BLANKET LOAD).

THIS IMPOSED LOAD DOES NOT MEET THE CRITERIA.
 BS 6399-1:1996 WITH REGARDS LOADING FOR 'MUSEUM
 FLOORS & ART GALLERIES FOR EXHIBITION PURPOSES'.

ASSUMING AN EARTH LOAD OF 18 kN/m³. THE ALLOWABLE
 DEPTH OF EARTH IN PLANTERS IS $\frac{3.5}{18} = \underline{200 \text{ mm}}$

THE ALLOWABLE DEPTH OF WATER = $\frac{3.5}{10} = \underline{350 \text{ mm}}$

ANY COMBINATION OF THESE FIGURES CAN BE USED
 TO KEEP THE ALLOWABLE IMPOSED LOAD TO 3.5 kN/m².

Table 1 — Minimum imposed floor loads (continued)

Type of activity/occupancy for part of the building or structure	Examples of specific use	Uniformly distributed load kN/m ²	Concentrated load kN
C Areas where people may congregate	Public, institutional and communal dining rooms and lounges, cafes and restaurants (See note 2)	2.0	2.7
C1 Areas with tables	Reading rooms with no book storage	2.5	4.5
	Classrooms	3.0	2.7
C2 Areas with fixed seats	Assembly areas with fixed seating (See note 3)	4.0	3.6
	Places of worship	3.0	2.7
C3 Areas without obstacles for moving people	Corridors, hallways, aisles, stairs, landings etc. in institutional type buildings (not subject to crowds or wheeled vehicles), hostels, guest houses, residential clubs, and communal areas in blocks of flats not covered by note 1. (For communal areas in blocks of flats covered by note 1, see A)	3.0 3.0	4.5 4.0
	Corridors, hallways, aisles, stairs, landings, etc. in all other buildings including hotels and motels and institutional buildings	4.0	4.5
	Corridors, hallways, aisles, etc., subject to wheeled vehicles, trolleys etc.	5.0	4.5
	Stairs and landings (foot traffic only)	4.0	4.0
	Ⓐ Light duty walkways — (access suitable for one person, walkway width approximately 600 mm) Ⓒ	3.0	Ⓐ 2.0 Ⓒ
	Ⓐ General duty walkways — (regular two-way pedestrian traffic) Ⓒ	5.0	Ⓐ 3.6 Ⓒ
	Ⓐ Heavy duty walkways — (high density pedestrian traffic including escape routes) Ⓒ	7.5	4.5
	Museum floors and art galleries for exhibition purposes	4.0	4.5
	Balconies (except as specified in A)	Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
	Fly galleries	4.5 kN/m run distributed uniformly over width	—
C4 Areas with possible physical activities	Dance halls and studios, gymnasias, stages	5.0	3.6
Ⓐ (See clause 5, Note 1, Note 2 and Note 3) Ⓒ	Drill halls and drill rooms	5.0	9.0
C5 Areas susceptible to overcrowding	Assembly areas without fixed seating, concert halls, bars Ⓐ and places of worship (See Note 4) Ⓒ	5.0	3.6
Ⓐ (See clause 5, Note 1, Note 2 and Note 3) Ⓒ	Stages in public assembly areas	7.5	4.5
D Shopping areas	Shop floors for the sale and display of merchandise	4.0	3.6

APPENDIX D

SUPPORT STEELWORK ASSESSMENT

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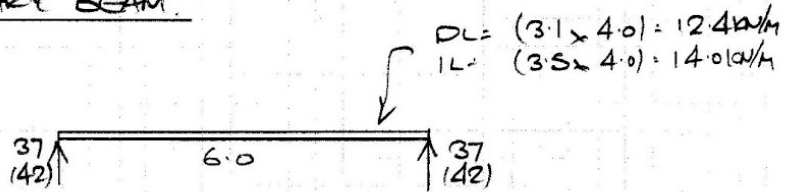
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CONTRACT

IRWELL HOUSE

PART OF STRUCTURE

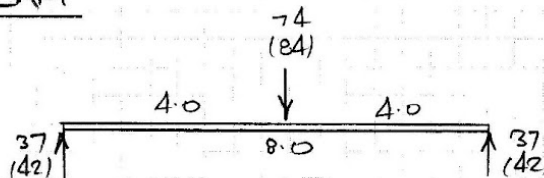
STEELWORK DESIGN CHECK.SECONDARY BEAM.

$$M = [(1.4 \times 12.4) + (1.6 \times 14.0)] \times \frac{6.0^2}{8} = 179 \text{ kNm}$$

CHECK 406 x 140 UB 46

 $L_e = 1.0 \text{ m}$ $M_b = 214 \text{ kNm}$

$$S_{PLH} = \frac{5 \times (12.4 + 14.0) \times 6000^4}{384 \times 210 \times 10^3 \times 15700 \times 10^4} = 13.5 \text{ mm} \quad \left(\frac{\text{SPAN}}{444} \right)$$

EX. 406 x 140 UB 46 ADEQUATEMAIN BEAM

$$M = [(1.4 \times 37) + (1.6 \times 42)] \times 4.0 = 476 \text{ kNm}$$

CHECK 457 x 152 UB 82

 $L_e = 1.0 \text{ m}$ $M_b = 480 \text{ kNm}$

$$S_{PLH} = \frac{(74 + 84) \times 8000^3 \times 10^3}{48 \times 210 \times 10^3 \times 36600 \times 10^4} = 21.2 \text{ mm} \quad \left(\frac{\text{SPAN}}{365} \right)$$

EX. 457 x 152 UB 82 ADEQUATE

// BUILDING INTEGRATED TECHNICAL FOOD SYSTEMS //

VOLUME 2 of 2

Andrew Jenkins
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Ph.D.

School of Natural and Built Environment

Queen's University Belfast

2018

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APPENDIX

C

APPENDIX C

Correspondence with Aquaponics UK

E-mail correspondence between Andrew Jenkins (Lead Technical Designer of the elevated aquaponic system) and Rebecca Bainbridge (Aquaponics UK). This documents the discussion in which the number of fish tanks and stocking densities were calculated for the elevated aquaponic system, noted in Chapter 5.0, subsection **5.3.2 - Elevated Aquaponic System - Early Designs**.

On 8 Oct 2012, at 11:31, Andy Jenkins wrote:

Hi Becky.

It is Andy here from the Biospheric Project.

We are now on our first day so the gears have started moving.

We are currently in the process of designing the system ready to discuss with the structural engineer.

Just a quick question; what density of tilapia would you normally work to per m³?

Last time we discussed a three tank fish system, from fry to adults, so maybe the size and stockings densities of these in a standard system.

We are just working out the loadings and where the tanks may be situated.

Regards,

Andy.

On 8 Oct 2012, at 13:21, Rebecca Bainbridge wrote:

Hi Andy,

The density depends on the age of the fish however we work to a maximum of 30kg/m³. You could probably go higher but this fits within the RSPCA freedom foods standards for fish and is below the level where pure oxygen is required (it's expensive!).

In a three tank system stocking at 20 grams, you can split the production cycle up into 3 parts: 20-100g, 100-260g, 260-450g. each taking approximately 60 days, with respective stocking densities of 20, 25 and 30 kg/3. As we discussed you can either have 3 different sized tanks, or 3 tanks of the same size and vary the water depth to achieve these densities.

Does that answer your question? To determine what tank size we need we really need to know the number of fish which is dictated by the area available, has this been decided? Let me know if you need more detail or anything else!

*Cheers,
Becky*

On 8 Oct 2012, at 13:36, Andy Jenkins wrote:

That is excellent Becky.

I am starting to get a grasp now of the maths involved now.

I am going off what Charlie said in the last meeting that '150Kg of fish = 100m² growing space'.

The grow space on the roof will be around 130m². Using the data Charlie mentioned I have calculated that the weight of fish need would be 195Kg, which at a stocking density of 30kg/m³ would be 6.5 tons.

Just using this as a hypothetical exercise, how many fish would we have in each of the three tanks, using the stocking densities you mentioned previously of 20, 25, and 30Kg/m³?

We are working hypothetically at this stage so we can discuss the loadings required with the structural engineer on friday to determine what is possible.

*Thanks,
Andy.*

On 8 Oct 2012, at 14:45, Rebecca Bainbridge wrote:

Hi Andy,

The 150kg = 100kg is a very simple estimation and a teeny bit low, and it would probably be more like 165kg of fish.

with 130m², if we divided this equally between media and raft tanks (was this for one greenhouse system or two?). There would be a total average standing biomass of 162.5kg. However it is more complicated than this as this is based on an average feeding rate across the system of 3% body weight per day. This actually fluctuates across a cycle and so does the total biomass. But this can definitely be used as a guide. The total number of fish stocked for each cycle would be around 475 (3 of these stockings per year), this would decrease through mortalities across the cycle with survival rates of 97%, 98% and 99% for each growth stage (quite a conservative estimate - in reality survival will probably be better with tilapia). So that will give you an idea of numbers.

Again this is based on a mix of media and raft (media values are half that of rafts i.e half as much fish per m²).

So for 65 m² of rafts values would be 108.3kg standing stock, 315 fish stocked per time and 800kg annual fish production.

Does that make sense?

Becky

On 8 Oct 2012, at 15:15, Andy Jenkins wrote:

Hi Becky,

(This is for the greenhouse on the roof)

So, 165kg fish for 100m² of growing space split between raft and media growing (as a working estimate).

How did you arrive at 162.5Kg standing biomass? Does standing biomass refer to the biomass of the fish alone?

Are you saying that in each tank stage, of the 3 stage system, there would be 475 fish. The first tank containing 475 fish at 20-100g, the second tank with 475 fish at 100-260g, and for the final stage 475 fish at 260-450g?

Just asking this for clarification so when I am chatting with the structural engineer I can justify the workings.

The info I need really is the number of fish per tank for a 100m² growing area (split between raft and media).

Thank you so much for helping me with this.

Andy.

On 8 Oct 2012, at 15:58, Rebecca Bainbridge wrote:

Hi Andy,

162.5g comes from a rule of thumb of 50g of fish food per m² of plant area and a fish feeding rate of 3% of their body weight per day, but as i said the fish do not require the same feeding rate across the production cycle, it is higher for small fish than larger fish which only require around 1% of their body weight per day.

Yes at any one time there would be around 475 fish per tank (although slightly less in larger tanks due to mortalities across the production cycle) e.g there may be 475 at 20-100g, 461 at 100-260g and 452 at 260-450g.

For 100m² this will be 365, 354 and 347 fish, and biomasses of 35.42kg, 90.21 kg and 154.57 kg for each tank.

No, worries I hope i'm explaining it ok!

Becky

On 9 Oct 2012, at 11:52, Andy Jenkins wrote:

Hi Becky.

These are the calculations I ended up with yesterday based on the figures we discussed.

Small Tank: @ 20kg/m² with 365 fish to a max of 100g per fish = 1.825m³ (2m³)

Medium Tank: @ 25Kg/m³ with 354 fish to a max of 260g per fish = 3.682m³ (4m³)

Large Tank: @ 30Kg/m³ with 347 fish to a max of 450g per fish = 5.205m³ (6m³)

There are a couple of questions from here on.

The first is if we had 2 species could we, based on the bracketed figures, house 1 species in:

Small tank 1m³

Medium Tank 2m³

Large Tank 3m³

Then house a second species in:

Small tank 1m3

Medium Tank 2m3

Large Tank 3m3

This would match the total water needed but divided by 2 species. Is this possible?

The second question is; can these 'tanks' be split into smaller tanks? This question is looking toward spreading the load over a wider area.

i.e.. can the small tank be a single tank at 1m3

medium tank be two tanks at 1m3 but linked together

and the large tank be split into three tanks at 1m3 and linked together.

So over the 2 species we would have

small tank = 2 1m3 tanks

Medium tank = 4 1m3 tanks

Large tank = 6 1m3 tanks.

I realise that these figures are extremely simplified but as a working example to give us an idea of water loading, is this possible?

On a side note to this.

Will we need to register with the Cefas using the 'RW2 Application to Register an Aquatic Animal Holding' form to allow our fish to be eaten? If so would you be able to help with water types etc.?

Sorry to be a pain.

Andy.

On 10 Oct 2012, at 11:14, Andy Jenkins wrote:

Hi Becky,

Have you had any thoughts regarding the comments below?

Thanks,

Andy.

On 10 Oct 2012, at 15:04, Rebecca Bainbridge wrote:

Hi Andy,

sorry have not been at my computer since early yesterday morning as was installing a system at a school,

if you want more but smaller tanks the best thing to do is have more tanks per production cycle i.e. stock less fish more often. This allows you to harvest more often too i.e harvest every month rather than every 2 months.

so you would have 189 fish per stocking and maximum biomass of 9.7, 18.4, 32.9, 47.3, 64.5, 81.5kg at each stage and would therefore need 0.5, 0.9, 1.3, 1.9, 2.2, and 2.5 m³ of water for each tank.

you could arrange production then like in the following illustration:

<PastedGraphic-1.pdf>

N tanks would be 1m³, and you could either have 4 G tanks at 2.5m³ so you only have to grade fish once (it is best to minimise grading as it stresses the fish). or 2 2m³ G tanks and 2 2.5m³ G tanks and grade twice.

All tanks would be linked by pipe not just the individual age classes as this is what ensures a constant level of nutrients to the plants across the growth cycle.

Does that make sense?

I'll be in the office all afternoon (and probably evening!) if you have any questions.

all best,

Becky

On 10 Oct 2012, at 15:12, Andy Jenkins wrote:

Hi Becky,

Thanks for getting back to me.

Would it be possible to have a telephone conversation regarding this?

2.5m³ is still a huge amount of water to be sat in one place. 15.6 tons of water!

I worked out that, based on the information, our entire water system would be 10.7 tons to support the amount of fish that, would in turn, support 100m² growing space.

Thanks,

Andy.

- End of correspondence -

APPENDIX

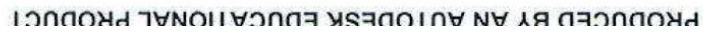
D

APPENDIX D

Structural Report - MB Structures April 2012 Revision A **(Addition of Appendix E)**

APPENDIX E

PROPOSED LOADING ASSESSMENT



Each tank = 1m x 1m x 1m = 1 ton

PROPOSED WORKING ON
EX. SECOND FLOOR SUB.

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CONTRACT IRWELL HOUSE	PART OF STRUCTURE		

SECONDARY BEAM CHECK - WITH TANKS

$IL = (1.6 \times 10.0) = 16.0 \text{ kN/m}$
 $DL = (1.4 \times 3.1) = 4.3 \text{ kN/m}$
 $IL = (1.6 \times X) = 1.6X$

EX. BEAM - 406 x 140 UB 46.

$L_e = 1.0 \text{ m}$ $M_b = 214 \text{ kNm}$

$W \times 6.0^2 / 8 = 214 \text{ kNm}$ $W = 48 \text{ kN/m (FACTORED)}$

LOAD ON SECONDARY BEAM

$= [(4.3 \times 4.0) + (16.0 \times 1.0) + (1.6X \times 4.0)] = 48 \text{ kN/m}$
 $1.6X \times 4.0 = 14.8 \text{ kN/m}$
 ALLOWABLE IMPOSED LOAD = 2.3 kN/m^2

THIS IMPOSED LOAD IS EQUIVALENT TO AN OFFICE LOADING

$DL = (3.1 \times 4.0) = 12.4 \text{ kN}$
 $IL = (10.0 \times 1.0) + (2.3 \times 4.0) = 19.2 \text{ kN}$

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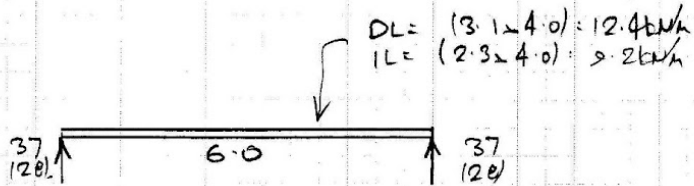
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DRAWING REF.

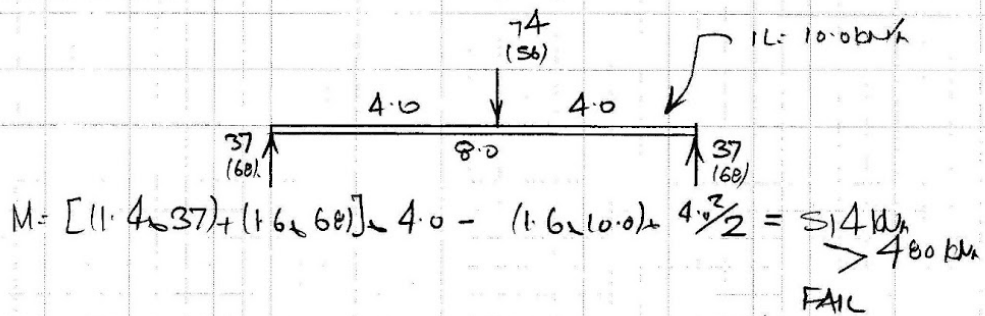
CONTRACT
IRWELL HOUSE

PART OF STRUCTURE

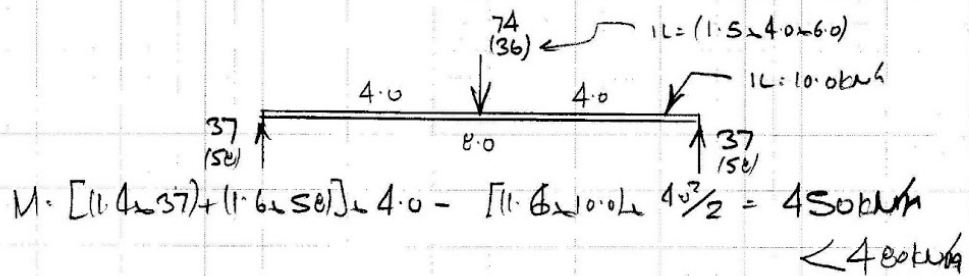
SECONDARY BEAM 'B' - NO TANKS



MAIN BEAM CHECK - WITH TANKS



REDUCE IMPOSED LOAD ON SLAB TO 1.5 kN/m^2



THIS IMPOSED LOAD IS EQUIVALENT
TO HOUSE LOADING.

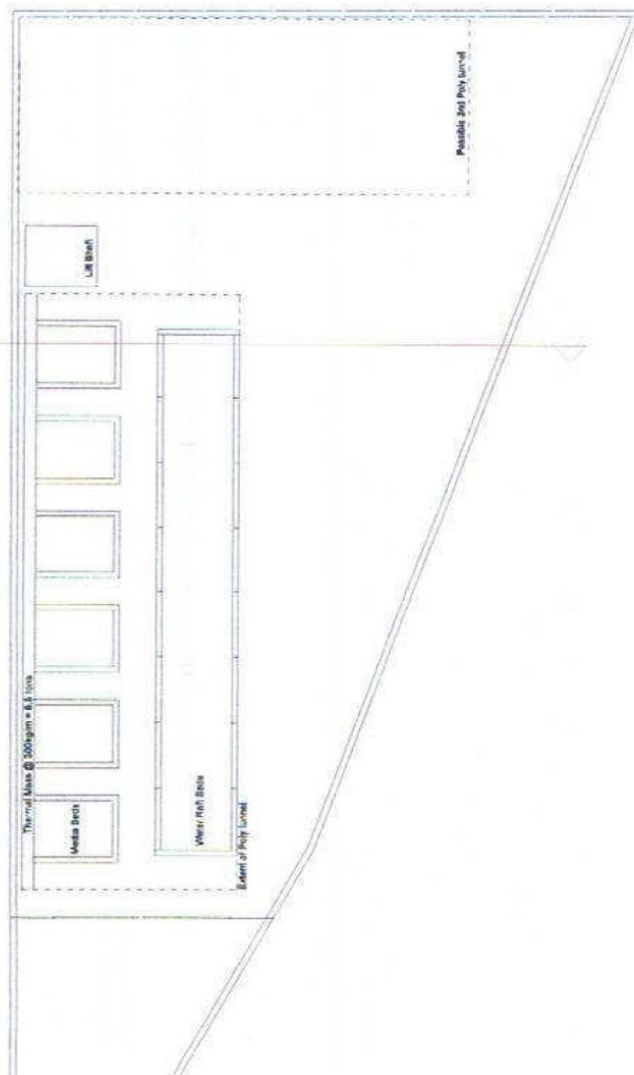
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IMPOSED LOADING = 1.5 kN/m^2 TO SLAB
 AREAS SURROUNDING THE TANKS.
 $1.5 \text{ kN/m}^2 = 150 \text{ kg/m}^2$
 SLAB AREA = $(6.0 \times 4.0) = 24.0 \text{ m}^2$
 TOTAL LOAD = $(24.0 \times 150) = 3600 \text{ kg}$

ASSUMING AN AVERAGE PERSON WEIGHT OF 100 kg .
 $3600/100 = 36$ NO. PEOPLE CAN BE IN 1 NO. BAY AT
 ONE TIME

THIS NUMBER IS EXCESSIVE & IT IS RECOMMENDED
 THAT THIS NUMBER BE KEPT TO A MAXIMUM
 OF 15 NO. PEOPLE IN EACH BAY AT ANY ONE TIME
 THIS REPRESENTS A LOADING OF $(15 \times 100) = 1500 \text{ kg/m}^2$
 WHICH IS EQUIVALENT TO A DOMESTIC LOADING

Plan:



Total Weights and Calculations based on:

Area of Poly tunnel = 173m²

Water Raft Beds (Water only) @ 10.2m x 2.82m x 0.35m = 18.9 tons

Water Raft Beds (Timber surrounds) @ 74 sections x 30kg = 2.2 tons

total = 21.1 ton

Media Grow Beds @ 7m² x 0.35m = 2.45m³

Option A - Expanded Clay @ 0.76 ton (per bay) = 4.58 ton

Option B - Perlite @ 0.27 ton (per bay) = 1.62 ton

Timber surrounds @ 0.44 ton (per bay) = 2.04 ton

Timber + Clay = @ 1.03 ton (per bay) = 6.18 ton

Timber + Perlite @ 0.71 ton (per bay) = 4.26 ton

Thermal wall = 6.8 tons

Option A - (21.1 ton + 6.18+6.8)/173 = 196kg/m²

Option B - (21.1 ton + 4.26+6.8)/173 = 185 kg/m²

WORST CASE LOADING

- WATER RAFT BEDS

IL = $(0.35 \times 10) = 3.5 \text{ kN/m}^2$

ASSUMING SLAB IS AS FLOORS

FLOOR IS ACCEPTABLE.

CONTRACTOR TO CONFIRM EXACT

ROOF SLAB MAKEUP

PROPOSED LOADING ASSESSMENT

ROOF

The roof slab is to support the loading from a polytunnel which houses water raft and growing beds.

Each of the water raft beds has approximately 350mm height of water in it. This equates to an imposed loading on the slab of 3.5KN/m^2 . Previous calculations showed the slab to be capable of supporting this load. This assumes that the roof slab is of a similar construction to the floor slabs.

The exact roof slab make up is to be determined when breaking out works are carried out to install the staircase.

APPENDIX

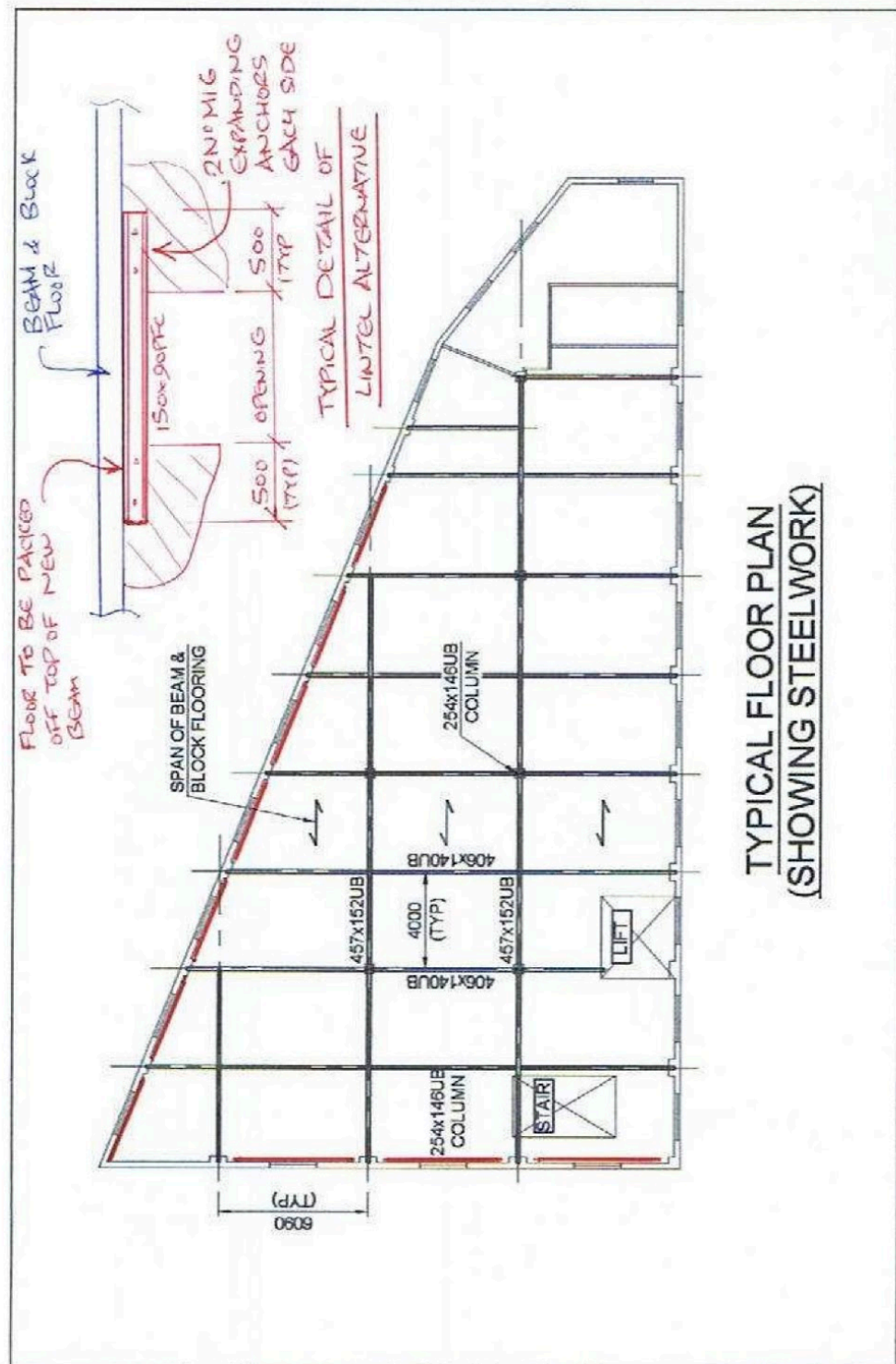
E

APPENDIX E

Structural Report - MB Structures April 2012 Revision B **(Addition of Appendix F)**

APPENDIX F

PROPOSED LINTEL ALTERNATIVE



**TYPICAL FLOOR PLAN
(SHOWING STEELWORK)**

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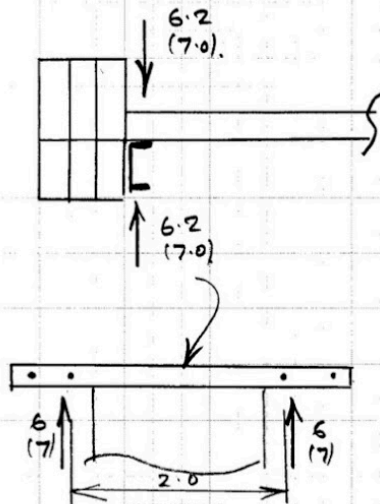
CONTRACT
12 WELL HOUSE

PART OF STRUCTURE

LINTEL ALTERNATIVE

$$PL = (3.1 \times 2.0) = 6.2 \text{ kN/m}$$

$$IL = (3.5 \times 2.0) = 7.0 \text{ kN/m}$$



$$M = [(1.4 \times 6.2) + (1.6 \times 7.0)] \times 2.0^2 / 8 = 10.1 \text{ kNm}$$

TRY 150x90 PFC $L_e = 2.0 \text{ m}$

$$M_b = 43 \text{ kNm}$$

$$S_{PLATE} = \frac{S_x (6.2 + 7.0) \times 2000^4}{384 \times 210 \times 10^3 \times 2324 \times 10^4} = 0.7 \text{ mm (SPAN / 3549)}$$

ADOPT 150x90 PFC LINTELS.

BOLT SHEAR : $[(1.4 \times 6) + (1.6 \times 7)] = 20 \text{ kN}$

ADOPT M16 EXPANDING ANCHORS.

APPENDIX

F

APPENDIX F

Structural Calculations - MB Structures January 2013

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	DESIGNER MB	DATE Jan ' 13	CHECKED	
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CONTRACT IRWELL HOUSE	PART OF STRUCTURE			

STRUCTURAL DESIGN CALCULATIONS FOR ROOF ASSESSMENT & PROPOSED LINTELS

AT

IRWELL HOUSE
EAST PHILIP STREET
SALFORD
M3 7LE

Prepared by - Mark Brooker CEng MStructE

Checked by - 

Date - January 2013

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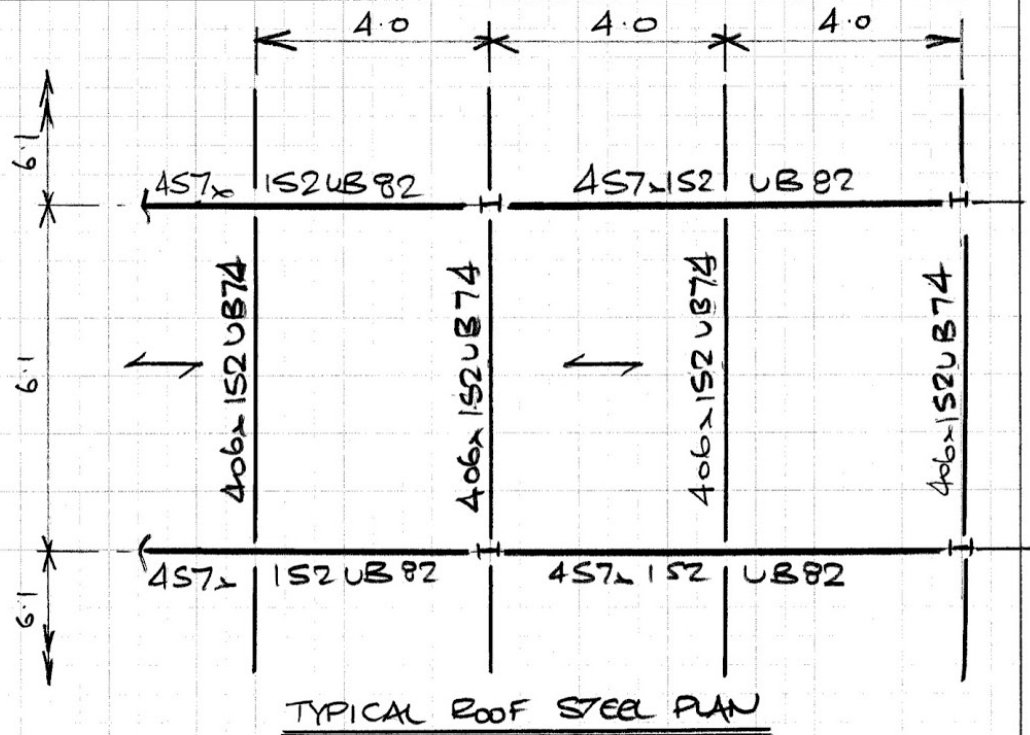
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Jan '13

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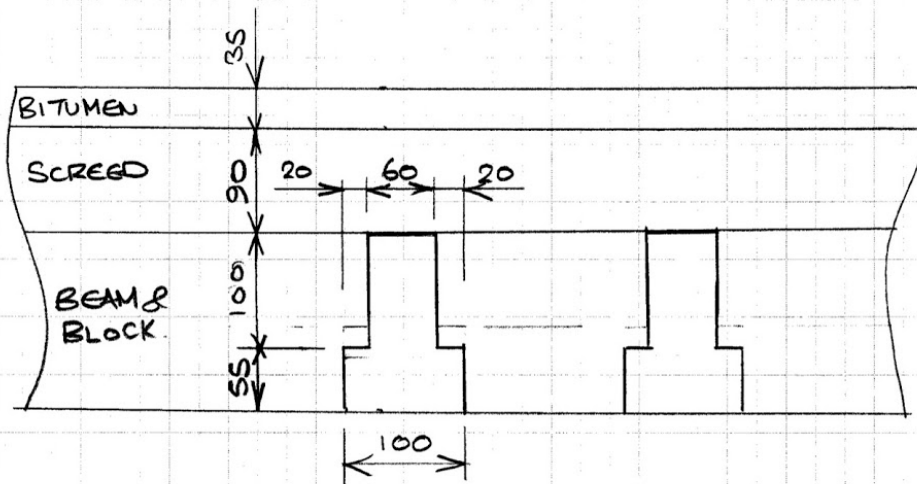
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DRAWING REF.

CONTRACT
IRWELL HOUSE

PART OF STRUCTURE

EXISTING ROOF AS MEASURED ON SITE - 17/1/13



DEAD LOAD

$$\begin{aligned}
 &35\text{mm BITUMEN} \quad (0.035 \times 13) = 0.5 \text{ kN/m}^2 \\
 &90\text{mm SCREED} \quad (0.09 \times 24) = 2.2 \text{ kN/m}^2 \\
 &\text{BEAM & BLOCK FLOOR} \\
 &\quad \text{BEAMS} \quad [(0.055 \times 0.1) + (0.06 \times 0.1)] \times 24 = 0.28 \text{ kN/m} \\
 &\quad \text{BEAMS AT 220mm c/c} \quad (100\% / 220 \times 0.28) = 1.3 \text{ kN/m}^2 \\
 &\quad \text{BLOCKS} = 1.0 \text{ kN/m}^2
 \end{aligned}$$

TOTAL DEAD = 5.0 kN/m²

TABLE NO. 3.9 PROPERTIES OF BEAMS TO BRITISH STANDARD 4. 1932					
IMPERIAL UNITS See separate page for notes					
Ref No.	Size D x B	Approximate Mass/ft	Metric D x B	Equivalent Mass/m	Obtain Properties from table no:-
	ins	Ibs	mm	kg	
BSB 101	3 x1.50	4	76x38	6	3.7 or 3.8
BSB 102	3 x3	8.5	76x76	13	3.7
BSB 103	4 x1.75	5	102x44	7	3.7 or 3.8
BSB 104	4 x3	10	102x76	15	3.8
BSB 105	4.75x1.75	6.5	121x44	10	3.7
BSB 106	5 x3	11	127x76	16	3.7
BSB 107	5 x4.50	20	127x114	30	3.8
BSB 108	6 x3	12	152x76	18	3.7 or 3.8
BSB 109	6 x4.50	20	152x114	30	3.7
BSB 110	6 x5	25	152x127	37	3.7 or 3.8
BSB 111	7 x4	16	178x102	24	3.7
BSB 112	8 x4	18	203x102	27	3.7 or 3.8
BSB 113	8 x5	28	203x127	42	3.7
BSB 114	8 x6	35	203x152	52	3.7 or 3.8
BSB 115	9 x4	21	229x102	31	3.7 or 3.8
BSB 116	9 x7	50	229x178	74	3.8
BSB 117	10 x4.50	25	254x114	37	3.8
BSB 118	10 x5	30	254x127	45	3.7
BSB 119	10 x6	40	254x152	60	3.8
BSB 120	10 x8	55	254x203	82	3.8
BSB 121	12 x5	32	305x127	48	3.7
BSB 122	12 x6	44	305x152	66	3.7
BSB 123	12 x6	54	305x152	69	3.7
BSB 124	12 x8	65	305x203	97	3.8
BSB 125	13 x5	35	330x127	52	3.8
BSB 126	14 x6	46	356x152	69	3.7
BSB 127	14 x6	57	356x152	85	3.7
BSB 128	14 x8	70	356x203	104	3.8
BSB 129	15 x5	42	381x127	63	3.7
BSB 130	15 x6	45	381x152	67	3.8
BSB 131	16 x6	50	406x152	74	3.8
BSB 132	16 x6	62	406x152	92	3.7
BSB 133	16 x8	75	406x203	112	3.8
BSB 134	18 x6	55	457x152	82	3.8
BSB 135	18 x7	75	457x178	112	3.7
BSB 136	18 x8	80	457x203	119	3.8
BSB 137	20 x6.50	65	508x165	97	3.8
BSB 138	20 x7.50	89	508x191	132	3.7
BSB 139	22 x7	75	559x178	112	3.8
BSB 140	24 x7.50	95	610x191	141	3.10

Notes relative to Tables 3.7 to 3.10 inclusive
These tables list most of the properties of British Standard Beams over the period 1903 to 1959 when these sections were replaced by Universal Beam and Column sections.

Three separate issues of British Standard 4 are relevant viz:-

BS4 1903

British Standard Beams with reference BSB [later classed as *old* British Standard Beams] shown in Table 3.7.

BS4 1921

British Standard Beams with reference NBSB and British Standard Heavy Beams and Pillars with reference NBSHB [commonly classed as *new* British Standard Beams] shown in Table 3.8.

BS4 1932

British Standard Beams with reference BSB101 to BSB140. This consisted of a list of sizes taken from both the 1903 and 1921 ranges with *one* new section only, namely BSB140 - 24 inches x 7½ inches x 95lbs/ft.

These are shown in Table 3.9 and rather than repeat section properties reference is made to the previous tables. However, since the section reference BSB140 is new the properties are given in Table 3.10.

British Standard 4, 1903, 1921 and 1932 were of course issued before the adoption of the metric system in the United Kingdom and all properties were provided in Imperial units.

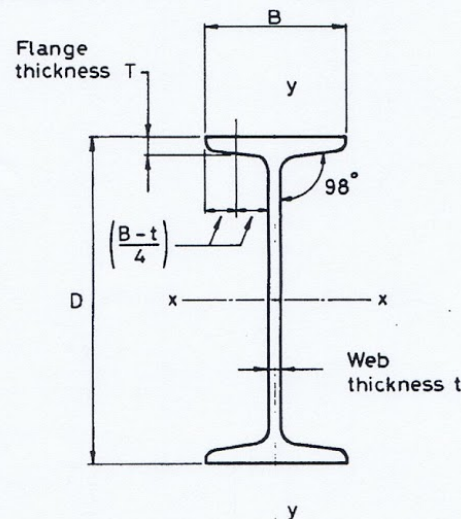


Figure 3.10 British Standard Beam.

TABLE NO. 3.8 PROPERTIES OF BEAMS TO BRITISH STANDARD 4 1921

IMPERIAL UNITS										See separate page for notes									
Ref. No.	Size D x B	Approximate Mass/ft	Metric Equivalent D x B	Mass/m	Thickness Web Flange	Area	Mom. of Inert. X - X Y - Y	Rad. of Gyr. X - X Y - Y	Sec. Mod. X - X Y - Y										
	ins	lbs	mm	kg	ins	ins ²	ins ⁴	ins	ins ³										
NBSB 1	3 x1.50	4	76x38	6	0.16	0.25	1.18	0.13	1.19	0.33	1.11	0.17							
NBSB 2	4 x1.75	5	102x44	7	0.17	0.24	1.47	0.19	1.58	0.36	1.83	0.21							
NBSB 3	4 x3	10	102x76	15	0.24	0.35	2.94	0.33	1.63	0.67	3.89	0.88							
NBSB 4	4.50x2	7	114x51	10	0.19	0.32	2.06	0.38	1.80	0.43	2.96	0.38							
NBSB 5	5 x2.50	9	127x64	13	0.20	0.35	2.65	0.79	2.03	0.55	4.36	0.63							
NBSB 6	5 x4.50	20	127x114	30	0.29	0.51	5.88	25.0	6.59	2.06	10.0	2.93							
NBSB 7	6 x3	12	152x76	18	0.23	0.38	3.53	21.0	1.46	2.44	0.64	7.00	0.97						
NBSB 8	6 x5	25	152x127	37	0.33	0.56	7.35	45.2	9.88	2.48	1.16	15.1	3.95						
NBSB 9	7 x3.50	15	178x89	22	0.25	0.40	4.42	35.9	2.41	2.85	0.74	10.3	1.38						
NBSB 10	8 x4	18	203x102	27	0.28	0.40	5.30	55.9	3.51	3.24	0.81	13.9	1.75						
NBSB 11	8 x6	35	203x152	52	0.35	0.65	10.30	115.1	19.54	3.34	1.38	28.8	6.51						
NBSB 12	9 x4	21	229x102	31	0.30	0.46	6.18	81.1	4.15	3.62	0.82	18.0	2.07						
NBSB 13	9 x7	50	229x178	74	0.40	0.83	14.71	208.1	40.17	3.76	1.65	46.25	11.48						
NBSB 14	10 x4.50	25	254x114	37	0.30	0.51	7.35	122.3	6.49	4.08	0.94	24.47	2.88						
NBSB 15	10 x6	40	254x152	60	0.36	0.71	11.77	204.8	21.76	4.17	1.36	40.96	7.25						
NBSB 16	10 x8	55	254x203	82	0.40	0.78	16.18	288.7	54.74	4.22	1.84	57.74	13.69						
NBSB 17	12 x5	30	305x127	45	0.33	0.51	8.83	206.9	8.77	4.84	1.00	34.49	3.51						
NBSB 18	12 x8	65	305x203	97	0.43	0.90	19.12	487.8	65.18	5.05	1.85	81.30	16.30						
NBSB 19	13 x5	35	330x127	52	0.35	0.60	10.30	283.5	10.80	5.25	1.03	43.62	4.33						
NBSB 20	14 x5.50	40	356x140	60	0.37	0.63	11.77	377.1	14.80	5.66	1.12	53.87	5.38						
NBSB 21	14 x8	70	356x203	104	0.46	0.92	20.59	705.6	66.70	5.85	1.80	100.80	16.70						
NBSB 22	15 x6	45	381x152	67	0.38	0.66	13.24	491.9	19.90	6.10	1.23	65.59	6.62						
NBSB 23	16 x6	50	406x152	74	0.40	0.73	14.71	618.1	22.50	6.48	1.24	77.26	7.49						
NBSB 24	16 x8	75	406x203	112	0.48	0.94	22.06	973.9	68.30	6.64	1.76	121.70	17.10						
NBSB 25	18 x6	55	457x152	82	0.42	0.76	16.18	841.8	23.60	7.21	1.21	93.53	7.88						
NBSB 26	18 x8	80	457x203	119	0.50	0.95	23.53	1292.0	69.40	7.41	1.72	143.60	17.40						
NBSB 27	20 x6.50	65	508x165	97	0.45	0.82	19.12	1226.0	32.60	8.01	1.31	122.60	10.00						
NBSB 28	22 x7	75	559x178	112	0.50	0.83	22.06	1677.0	41.10	8.72	1.36	152.40	11.70						
NBSB 29	24 x7.50	90	610x191	140	0.52	0.98	26.47	2443.0	60.40	9.61	1.51	203.60	16.10						

TABLE NO. 3.10 PROPERTIES OF SPECIAL BEAM TO BRITISH STANDARD 4 1932

IMPERIAL UNITS										See separate page for notes									
Reference No.	Size D x B	Approx. Mass/ft	Metric Equivalent D x B	Mass/m	Thickness Web Flange	Area	Mom. of Int. X - X Y - Y	Rad. of Gyr. X - X Y - Y	Sec. Mod. X - X Y - Y										
BSB 140	24x7.50	95	610x191	141	0.57	1.01	27.94	2533.0	62.5	9.52	1.50	211.1	16.7						

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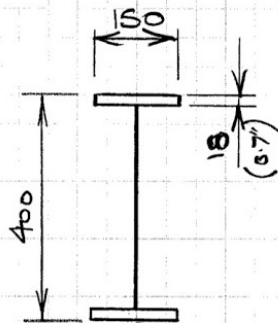
IRWELL HOUSE

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CHECK MAX CAPACITY OF EXISTING ROOF BEAMS

SECONDARY BEAM

STEEL ASSUMED TO BE
CIRCA 1950.



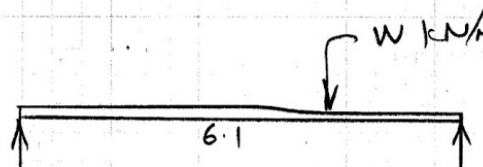
FROM HISTORICAL STEELWORK
MANUAL, BEAM ASSUMED TO
BE

406 x 152 UB 74

$$r_y = (6.48 \times 2.54) = 16.5 \text{ cm}$$

$$Z_x = (77.26 \times 16.3871) = 1266 \text{ cm}^3$$

SITE DIMENSIONS



$$I/r_y = 610/16.5 = 37$$

$$D/T = 406/18 = 23$$

$$P_{bcr} = 180 \text{ N/mm}^2$$

$$f_{bx} = M \times 10^3 / 1266 = 180$$

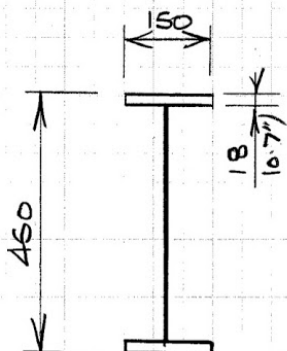
$$M = 228 \text{ kNm}$$

$$M = W \times 6.1^2 / 8 = 228$$

$$W = 49 \text{ kN/m} = \text{ALLOWABLE UDL}$$

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PRIMARY BEAM



FROM HISTORICAL STEELWORK
MANUAL, BEAM ASSUMED TO
BE

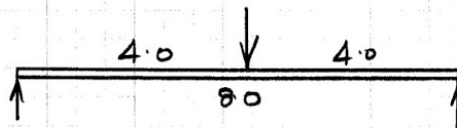
457x152UB 82

$$r_y = (1.21 \times 2.54) = 18.3 \text{ cm}$$

$$Z_x = (93.53 \times 16.3871) = 1533 \text{ cm}^3$$

SITE DIMENSIONS

PRIMARY BEAM SUPPORT SECONDARY BEAMS AT
MID-SPAN. THE EFFECTIVE LENGTH CAN THEREFORE
BE ASSUMED TO BE 4.0m



CHECK BEAM FOR

$$l/r_y = 400 / 18.3 = 22$$

$$D/T = 457 / 18 = 25$$

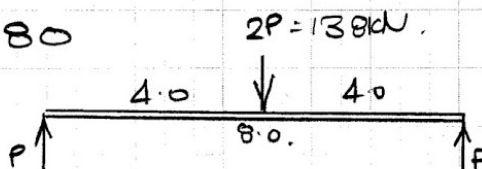
$$F_{bcx} = 180 \text{ N/mm}^2$$

$$f_{bx} = M \times 10^3 / 1533 = 180$$

$$M = 276 \text{ kNm}$$

$$M = (P \times 4.0) = 276 \text{ kNm}$$

$$P = 69 \text{ kN}$$



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CONTRACT IRWELL HOUSE		PART OF STRUCTURE	

FROM DETERMINING CAPACITY OF EX. PRIMARY BEAM.
 THE MAX. ALLOWABLE END REACTION TO THE SECONDARY BEAMS = 69KN.

A horizontal line representing a beam with a length of 6.1m. At each end, there is an upward-pointing arrow labeled '69', representing the end reactions.

$UDL = (2 \times 69) / 6.1 = \underline{\underline{22.6 \text{ kN/m}}}$

$M = (22.6 \times 6.1^2 / 8) = 105 \text{ kNm} < 294 \text{ kNm} \quad \text{O.K.}$

DEAD LOADING ON ROOF = 5.0 kN/m²
 BEAM SPACING = 4.0m

DEAD LOAD ON BEAM = (5.0 x 4.0) = 20.0 kN/m
 UDL CAPACITY REMAINING FOR IMPOSED LOAD
 $= (22.6 - 20.0) = 2.6 \text{ kN/m}$

ALLOWABLE IMPOSED LOAD = $2.6 / 4.0 = 0.65 \text{ kN/m}^2$

LOADING TO BS 449 INDICATES AN ALLOWABLE
 IMPOSED LOAD ON A FLAT ROOF OF 1.5 kN/m²

THE ROOF IMPOSED LOAD CAPACITY IS DICTATED BY
 THE PRIMARY BEAMS & AS SUCH THE CALCULATIONS
 HAVE SHOWN THERE TO BE NO SPARE CAPACITY
 WITHIN THE ROOF STRUCTURE.

Table 5.5 Comparison of roof loads to I.S.E.

Report published 1927	Report revised 1933
The following imposed loads apply to the horizontal and vertical projection of the roof	The following imposed loads deemed to include snow and wind
(i) Flat roofs with inclination not exceeding 15° to horizontal Vertical load 50 lb/sq ft Horizontal load 0 lb/sq ft	(i) On roofs with inclination not exceeding 10° to horizontal:— (a) Where no direct access 15lb/sq foot (b) Where direct access 30 lb/sq foot
(ii) Sloping roofs with inclination not exceeding 40° to horizontal Vertical load 25 lb/sq ft Horizontal load 10 lb/sq ft	(ii) On all roofs inclined at more than 10° to horizontal, curved and barrel roofs etc. without access. 10 lb/sq foot on plan taken as uniformly distributed over the slope of the roof plus the normal wind load.
(iii) Sloping roofs with inclination not exceeding 75° to horizontal Vertical load 15 lb/sq ft Horizontal load 15 lb/sq ft	
(iv) Sloping roofs with inclination exceeding 75° to horizontal to be treated as vertical surfaces.	
The above loads are to be considered as inclusive of temporary loads, snow and wind, and only apply to roofs in multi-storey steel frame buildings not exceeding 50 ft in span. However, the imposed load on a flat roof need not exceed the imposed load on the floor below.	

5.3.6 British Standard 449 1932

This specification gave a much simpler schedule of loading viz:—

Imposed loads

Floors of rooms used for domestic purposes	40lb/sq ft.
Offices — floors above entrance floor	50lb/sq ft
Offices — entrance floor and below	80lb/sq ft
Churches, reading rooms etc	70lb/sq ft
Retail stores	80lb/sq ft
Assembly Halls etc	100lb/sq ft
Flat Roofs	30lb/sq ft

Inclined Roofs — wind load only at 15lb/sq ft inwards on windward slope and 10lb/sq ft outwards on leeward slope

This substantially remained unaltered until 1948.

5.3.7 British Standard 449 1948

Ten categories of imposed load were tabulated. In addition to the distributed loads per square foot of area minimum loads on slabs and on beams were also given.

This is given as Table 5.6.

5.3.8 General

Sufficient information has been given to show the development of live or imposed loads over a long period of time. The publication of CP3 Chapter V 1952 and subsequent amendments transferred loadings from design specifications to separate documents.

CP3 Chapter V should be consulted for any required information subsequent to BS449 1948.

It is interesting to note that E.S. Andrews in his book Theory and Design of Structures (Fifth Edition 1932) gives a table comparing live loads in Britain and those concurrently in use in Canada, New York and Germany.

The figures quoted for Canada show substantial reductions on the ISE and LCC values which have already been quoted herein.

5.4 Wind Loads

From the very nature of the subject this has been one of the most difficult matters to resolve.

Prior to the Tay Bridge disaster in 1879 comparatively little attention was given to the subject by engineers, though Smeatons formula, published in 1759, ie 120 years earlier, proves that it had long been appreciated that forces due to wind pressure were both real and important.

Smeatons formula is given as:—

$$p = 0.005V^2$$

where p is the pressure or load in lbs/sq foot and V the velocity of the wind in miles/hour.

Following upon experiments at the National Physical Laboratory it was considered that Smeaton's formula gave results which were too high and the formula was altered to:—

$$p = 0.003V^2$$

Using this latter formula a wind velocity of 100 miles per hour gives a pressure of 30lbs/sq foot, but as such a velocity of wind would not normally be sustained, the average velocity would give a more realistic loading.

Prior to the erection of the Forth Railway Bridge Sir Benjamin Baker conducted experiments on wind loads by measuring the pressure on plates exposed to the wind.

Records of such experiments over a period from 1884 to 1890 gave the following average results:—

(a) On 1.5sq ft revolving gauge	27.6lb/sq ft
(b) On 1.5sq ft fixed gauge	29.8lb/sq ft
(c) On 300sq ft fixed gauge	16.9lb/sq ft

Subsequent to the erection of the Forth Railway Bridge records were kept on small fixed gauges 1.5sq ft in area placed at different heights above high water level. The average pressures recorded between 1901 and 1906 were:—

(a) At 50ft above high water level	13lb/sq ft
(b) At 163ft above high water level	23lb/sq ft
(c) At 214ft above high water level	29lb/sq ft
(d) At 378ft above high water level	50lb/sq ft.

It is on record that wind loads of 30, 40, 50 and even 56lb/sq ft have been specified by various authorities prior to the introduction of the L.C.C. loading in 1909.

In 1930 a volume, Wind Stresses in Buildings by Robins Fleming was published in USA. This details the investigation into wind loads at length and was accepted at that period as the most authoritative work on the subject.

Various specifications for wind loads are as follows:—

5.4.1 London County Council (General Powers) Act 1909

The requirements for loads on roofs which were deemed to include wind forces were given in item 5.3.4. and will not be repeated. The most important requirement is:—

"All buildings shall be so designed as to resist safely a wind pressure in any horizontal direction of not less than 30lb/sq ft of the upper two-thirds of the surface of such buildings exposed to wind pressure".

This requirement was strictly imposed in the design of buildings in London. It was also used outside London prior to the publication of the ISE Report.

5.4.2 Institution of Structural Engineers — Report on Steelwork for Buildings

Part 1 Loads and Stresses 1927

Apart from the loads on roofs which have already been specified (see 5.3.5.) the following simple requirement was given:—

MB STRUCTURES Ltd CIVIL & STRUCTURAL ENGINEERS 137 Barton Road, Stretford, Manchester, M32 8DN T 0161 865 0289 F 0161 865 6057 M 07799 327846 E mail@mbstructures.co.uk W www.mbstructures.co.uk	JOB No MB-1617		SHEET No 10
	DESIGNER M.B.	DATE Jan '13	CHECKED
	DRAWING REF.		
CONTRACT IRWELL HOUSE	PART OF STRUCTURE		

ALLOWABLE IMPOSED LOAD ON SECONDARY BEAMS SPANNING BETWEEN COLUMNS

ALLOWABLE LOAD = 63 kN/m
 - DEAD LOAD: (5.0 x 4.0) = 20 kN/m
 - ROOF IMPOSED (ORIGINAL) = (1.5 x 4.0) = 6 kN/m
 ALLOWABLE REMAIN = 37 kN/m

BEAM CAPACITY: (49 kN/m - 37 kN/m) = 12 kN/m

THE MAX. CAPACITY IN SECONDARY BEAMS SUPPORTED BY COLUMNS IS 12 kN/m

THIS IS EQUIVALENT TO A 1.0m WIDE
 x 0.65m DEEP TROUGH OF EARTH
 : (1.0 x 0.65 x 18) = 11.7 kN/m

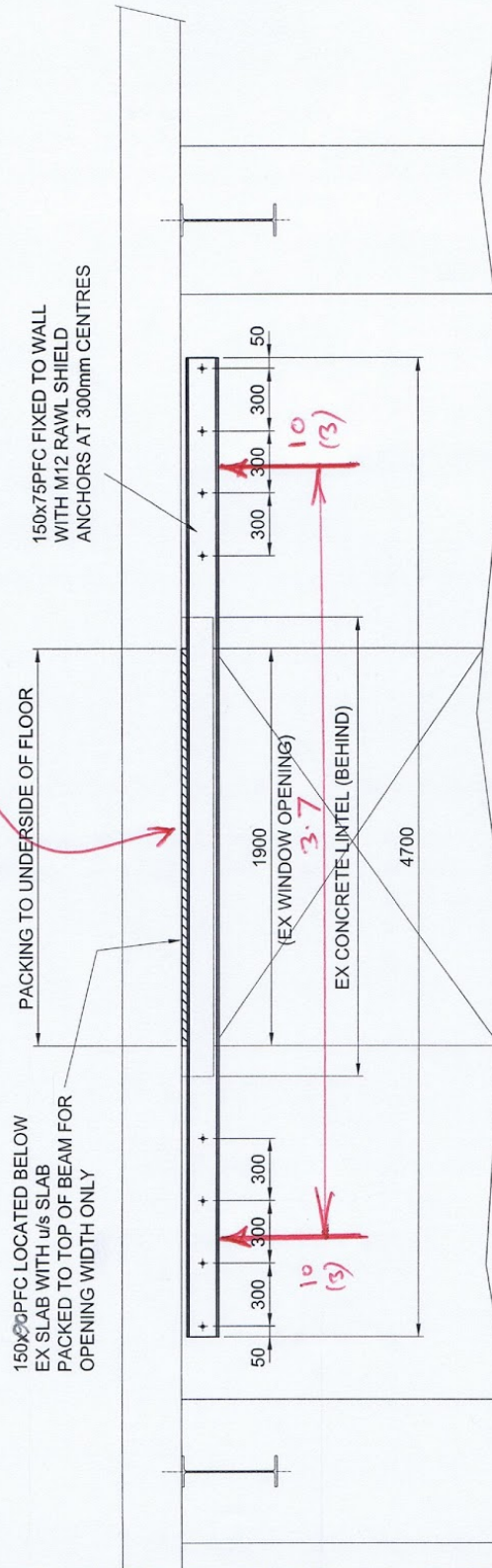


PLAN SHOWING LINTEL TYPES

NOTE
ALL DIMENSIONS & DETAILS TO BE
CONFIRMED ON SITE BY
CONTRACTOR PRIOR TO ORDERING /
FABRICATING STEELWORK

$$DL = (5.0 \times 2.0) = 10.0 \text{ kN/m}$$

$$IL = (1.5 \times 2.0) = 3.0 \text{ kN/m}$$



ELEVATION ON LINTEL 'A'

$$M = [(1.4 \times 10) + (1.6 \times 3)] \times 1.9$$

$$= [1.4 \times 10 + 1.6 \times 3] \times 1.9 / 2 = 26 \text{ kNm}$$

TRY 150x75 PFC $L_e = 3.7\text{m}$ $M_b = 32 \text{ kNm}$

$$S_{req} = \frac{5 \times (10.0 + 3.0) \times 3700^4}{384 \times 200 \times 10^3 \times 1162} \times 10^4 = 13.0 \text{ mm} \left(\frac{SPAN}{285} \right)$$

ADOPT 150x90 PFC

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	DESIGNER M.B.	DATE Jan '13	CHECKED
	DRAWING REF.		
CONTRACT IRWELL HOUSE	PART OF STRUCTURE		

BOLT DESIGN

UNFACTORED SHEAR TO BEAM ENDS
 $= (10 + 3) = 13 \text{ KN.}$

TRY RAWL SHIELD ANCHOR, - M12

SINGLE ANCHOR SHEAR RESISTANCE = 4.3 KN

Nº BOLTS REQ^d: $15 / 4.3 = 4 \text{ Nº BOLTS.}$

LOCATE BOLTS AT 300mm CENTRES TO ENSURE CAPACITY IS NOT EFFECTED BY SPACING.

Specification Data

RAWLBOLT® Shield Anchor Loose Bolt Performance Data

SIZE	CONCRETE, $f_{ck, cube} = 30 \text{ N/mm}^2$ (C20/25)										Brickwork = 20.5 N/mm ²
	CHARACTERISTIC RESISTANCE (kN)		DESIGN RESISTANCE (Factored) (kN)		RECOMMENDED LOAD (Unfactored) (kN)		CHARACTERISTIC EDGE DISTANCE (mm)		CHARACTERISTIC SPACING (mm)	RECOMMENDED LOAD (Unfactored) (kN)	
	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{rec})	SHEAR (V_{rec})	TENSION ($C_{cr,N}$)	SHEAR ($C_{cr,V}$)	TENSION & SHEAR ($C_{cr,N}$) ($C_{cr,V}$)	TENSION & SHEAR (N_{rec}) (V_{rec})	
M6	9.6	8.2	4.5	4.5	3.8	3.8	80	100	120	1.8	
M8	12.1	12.8	5.6	7.1	4.7	5.9	100	120	150	2.3	
M10	16.7	20.9	7.7	11.6	6.4	9.7	120	160	180	2.9	
M12	24.6	30.5	11.4	16.9	9.5	4.1	160	180	250	4.3	
M16	57.4	55.3	26.6	30.7	22.2	25.6	190	260	290		Bolts above M12 are not recommended in brickwork.
M20	79.4	88.1	36.8	48.9	30.7	40.8	250	300	330		
M24	99.0	122.8	45.8	68.2	38.2	66.8	280	350	420		

For further explanations on calculations please see pages 10 and 11

Reduction Factors - Edge and Spacing Distances for Rawlbolt Shield Anchor Loose Bolt

The full characteristic edge and spacing distances shown in the table above are the minimum allowable for the quoted DESIGN RESISTANCE or RECOMMENDED LOAD, depending on your design method.

Where these dimensions are not achievable, the

appropriate reduction factor/s from the tables below must be applied to the DESIGN RESISTANCE or RECOMMENDED LOAD.

Choose the required bolt diameter across the top of the appropriate table and read down the left hand column until actual edge or spacing distance is found.

Read off the reduction factor where the two

lines intersect (interpolate as required). Multiply this factor by the DESIGN RESISTANCE or RECOMMENDED LOAD quoted in the table. On the occasion that multiple close edge and/or spacing distances occur, the appropriate reduction factors must be applied.

Edge Distance (Concrete)

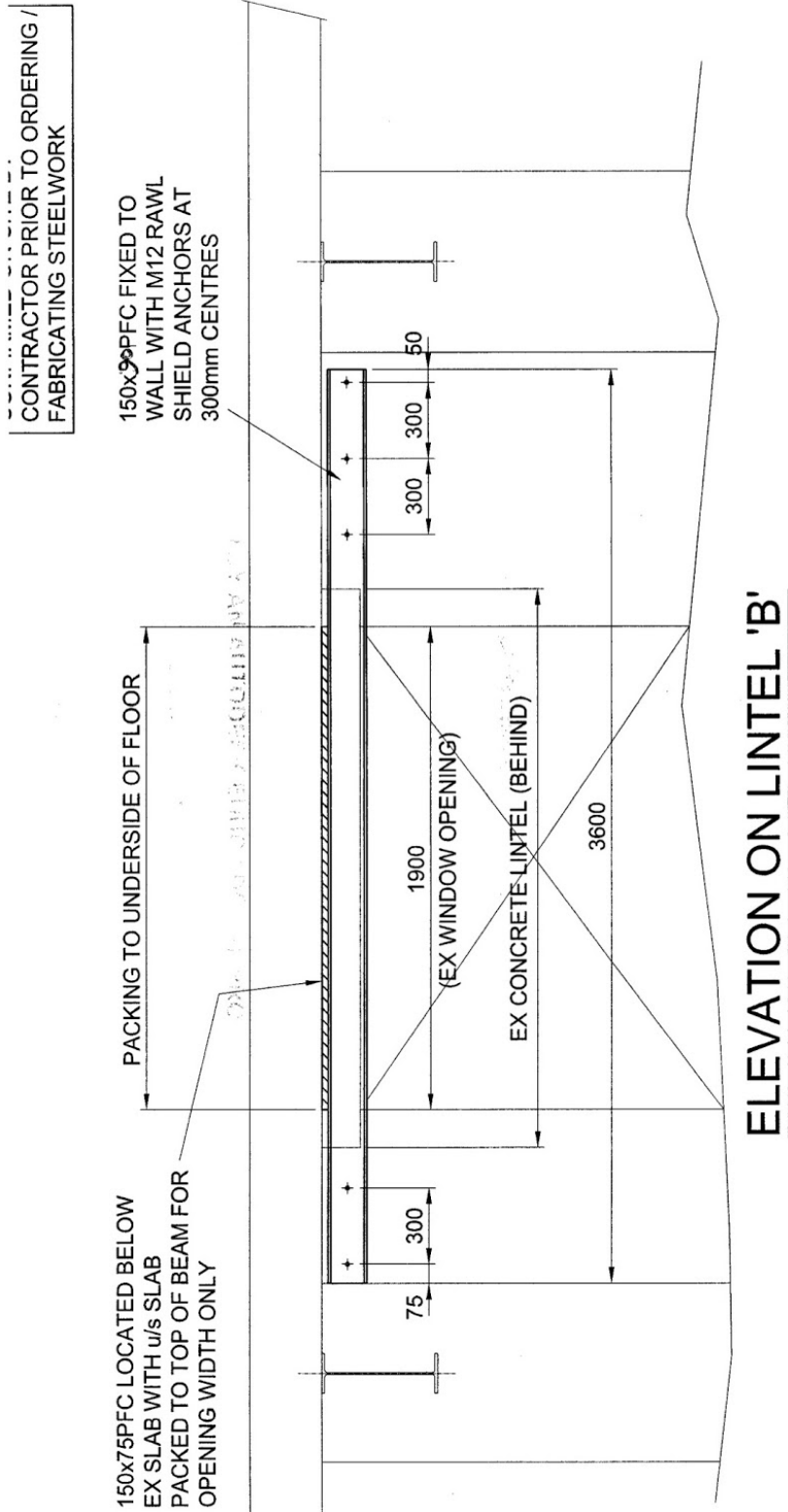
EDGE (mm)	TENSILE: EDGE REDUCTION FACTORS							EDGE (mm)	SHEAR: EDGE REDUCTION FACTORS						
	M6	M8	M10	M12	M16	M20	M24		M6	M8	M10	M12	M16	M20	M24
50	0.70							60	0.50						
60	0.80	0.70						70	0.64						
70	0.90	0.80	0.70					80	0.76	0.50					
80	1.00	0.90	0.80	0.70				100	1.00	0.75	0.50				
100		1.00	0.90	0.78	0.70			120		1.00	0.69	0.50			
120			1.00	0.85	0.78	0.70		160			1.00	0.85			
140				0.93	0.85	0.76	0.70	170				0.93	0.50		
160				1.00	0.93	0.82	0.76	180				1.00	0.55		
190					1.00	0.88	0.82	220					0.76	0.50	
220						0.94	0.88	260					1.00	0.75	0.50
250						1.00	0.94	300						1.00	0.75
280							1.00	350							1.00

Spacing (Concrete)

SPACING (mm)	TENSILE & SHEAR REDUCTION FACTORS						
	M6	M8	M10	M12	M16	M20	M24
60	0.70						
80	0.80	0.70					
100	0.90	0.80	0.70				
120	1.00	0.90	0.80	0.70			
150		1.00	0.90	0.78	0.70		
180			1.00	0.85	0.78	0.70	
210				0.93	0.85	0.78	0.70
250				1.00	0.93	0.85	0.76
290					1.00	0.93	0.82
330						1.00	0.88
370							0.94
420							1.00

Brickwork Application

When installing into brickwork and there is a combined load in tension and shear, the resultant load must not exceed the quoted performance figure.



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	DESIGNER M.B.	DATE Jan '13	CHECKED
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CONTRACT IRWELL HOUSE		PART OF STRUCTURE	

LINTEL TYPE 'B'
(REDUCED BEAM LENGTHS)

$DL = (5.0 \times 0.5) = 2.5 \text{ kN/m}$
 $IL = (11.5 \times 0.5) = 5.75 \text{ kN/m}$

$DL = (5.0 \times 1.4) = 7.0 \text{ kN/m}$
 $IL = (11.5 \times 1.4) = 16.1 \text{ kN/m}$

ADOPT 150x90 PFC
(BY INSPECTION)

BOLT DESIGN

UNFACTORED SHEAR TO BEAM ENDS: $(6+5) = 11 \text{ kN}$

TRY RAWL SHIELD ANCHOR - M12

SINGLE ANCHOR CAPACITY: 4.3 kN

Nº BOLTS REQº = LHS: $(3+3)/4.3 = 2 \text{ Nº BOLTS}$
 RHS: $(5+4)/4.3 = 3 \text{ Nº BOLTS}$

APPENDIX

G

APPENDIX G

Structural Calculations - BDP March 2013

STRUCTURAL CALCULATIONS

IRWELL HOUSE

MARCH 2013

BDP.

Irwell House, East Philip Street, Salford

Issue Record

Revision	Date	Issued to and purpose of issue
A	21/03/13	Issue to Client

Contents

1.0	Design Information	
1.1	Scope of Work	
2.0	Polytunnel at Roof level	
2.1	Existing and Proposed Loading	PTR 01 – PTR 09
2.2	Existing load on beams	PTR 10 – PTR 12
2.3	Proposed load on beams	PTR 13 – PTR 24
2.4	Existing / Proposed load on column	PTR 25
3.0	Polytunnel Supporting Beam	
3.1	Supporting Beam Design	PTB 01 – PTB 06
4.0	Second Floor Loading	
4.1	Existing / Proposed loading on beams	SFL 01 – SFL 08
5.0	Wind load	
4.1	Existing Condition	PTW 01 – PTW 03
4.2	Proposed Condition	PTW 04 – PTW 05
4.3	Resistance	PTW 06 – PTW 09
6.0	Lintel Design	
6.1	Lintel Type A	A1 – A5
6.2	Lintel Type B	B1 – B5
6.3	Lintel to B10 Wall	BW/1
7.0	Sketches / Extracts reference	

1.0 Design Information

1.1 Scope of Work

BDP structures were asked to carry out structural calculations of Irwell House, East Philip Street, Salford, to following up structural inspection and structural calculations done by MB Structures Ltd.

Building description can be found in 'Structural Investigation Report on Building' by MB Structures Ltd.

In this calculation package, it contains beams load capacity assessment at roof and second floor, wind load assessment, polytunnel supporting beam design and lintel design.

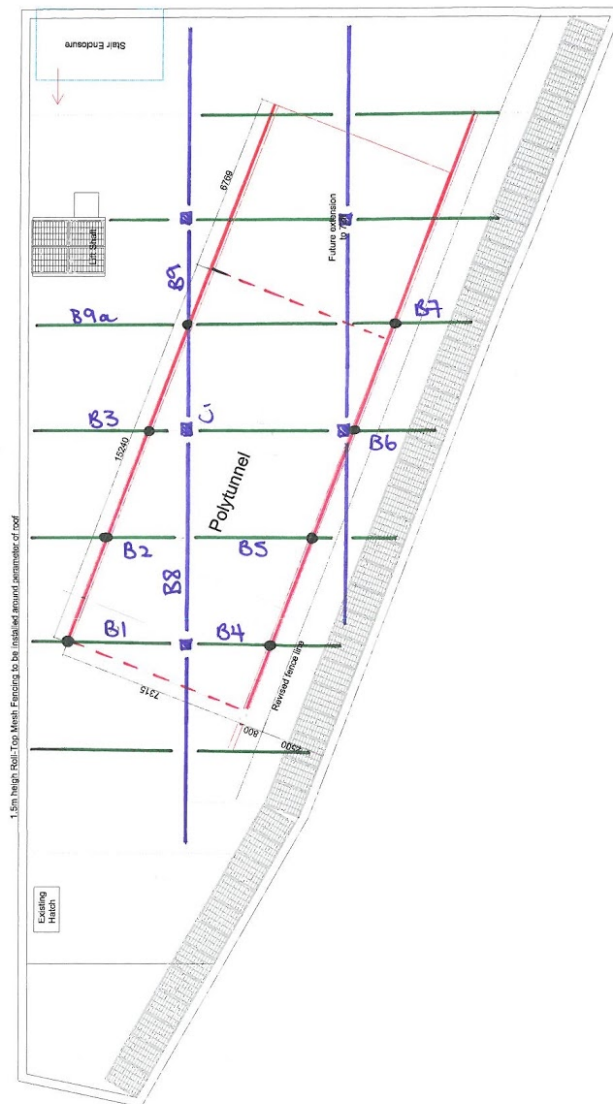
2.0 Polytunnel at Roof level

Without knowing the actual load capacity of the existing structure, it was agreed that a 10% increase in load capacity with the proposed loading would be acceptable for the beams. In the calculation, beams' bending moment and beam end reactions were calculated with existing and proposed loading, and then compared the before / after results.

For the existing load, it includes dead load of 5KN/m² determined by MB Structures, and imposed load of 0.6KN/m² as a minimum that the roof would take.

For the proposed load, it includes the existing load with the addition loads of the polytunnel, wind load on the polytunnel, and snow drift load with the polytunnel.

Overall all beams are within the 10% load capacity increase allowance.

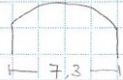


Root level.
Beam Reference
SK 01
1:200

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Poly tunnel @ Roof	PTR 01
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE
HL	March 13


REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Existing load @ Roof level</u></p> <p>Dead load</p> <p>As calculated previously by MR Structures.</p> <p>total dead = 5 kN/m^2</p> <p>$G_k = 5 \text{ kN/m}^2$</p> <p><u>Imposed load</u></p> <p>loading to BS+99 indicates an allowable imposed load on a flat roof 1.5 kN/m^2. However since actual load capacity is unknown take $Q_k = 0.6 \text{ kN/m}^2$ as minimum</p> <p>$Q_k = 0.6 \text{ kN/m}^2$</p> <p><u>Proposed load @ Roof level</u></p> <p>Dead load = 5 kN/m^2</p> <p>$G_k = 5 \text{ kN/m}^2$</p> <p><u>Imposed load</u></p> <p>- 0.6 kN/m^2</p> <p>Addition load.</p> <p>- Poly tunnel = $7.315 \text{ m} \times 15.240 \text{ m}$ $= 111.5 \text{ m}^2$</p> <p>$Q_k = 0.1 \text{ kN/m}^2$</p> <p>Estimate weight</p> <p>One hoop - $\phi 50.8 \text{ mm}$ (Assume 4mm thick)</p> <div>  <p>Hoop length = 11.5 m.</p> </div>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Root	PTR 02
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

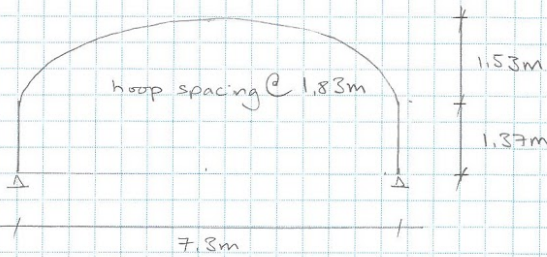
REFERENCE	CALCULATIONS	OUTPUT
	<p>Tube section =  4mm thick.</p> <p>Section area = $\pi \times 0.0254^2 - \pi \times (0.0254 - 0.004)^2$ $= 0.0006 \text{ m}^2$</p> <p>Steel density = 78 kNm^3</p> <p>\therefore one hoop = $78 \times 0.0006 \times 11.5$ $= 0.54 \text{ kN}$</p> <p>poly tunnel length = 15.24 m</p> <p>hoop spacing = 1.83 m $\frac{15.24}{1.83} = 8.3 \rightarrow 9 \text{ hoops}$</p> <p>ridge tube + foundation tubes $= 78 \times 0.0006 \times 15.24 \times 3$ $= 2.14 \text{ kN}$</p> <p>stabiliser bars = 0.5 kN/end estimate</p> <p>Total steel = $0.54 \times 9 + 2.14 + 0.5$ $= 7.5 \text{ kN}$</p> <p>Add 20% for addition load (Door frame + raser)</p> <p>$7.5 \times 1.2 = 9 \text{ kN}$</p> <p>$9 \text{ kN} / 11.5 \text{ m}^2 = 0.1 \text{ kN/m}^2$</p>	<p>0.54 / hoop.</p> <p>2.14</p> <p>0.5</p> <p>0.1 kN/m² Polytunnel load / sqm</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 03
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	Feb 13

REFERENCE	CALCULATIONS	OUTPUT
	<p>Roof level - Wind load to Poly tunnel:</p>  <p>hoop spacing @ 1.83m</p> <p>7.8m</p> <p>1.53m</p> <p>1.37m</p>	
	Wind load calculation to BS 6399-2	
Table 1	$k_b = 2$	
Fig 3	$H = 3m$ $C_r = 0.02$	
2.2.2.1	Site Wind Speed $V_s = V_b \times S_a \times S_d \times S_c \times S_p$	
Fig 6	@ Manchester $V_b = 23 \text{ m/s}$ Basic wind speed	$V_b = 23 \text{ m/s}$
2.2.2.2	altitude factor $S_a = 1 + 0.001 A_s$ $A_s = \text{site altitude} = 28m \text{ (Google Earth)}$ $S_a = 1 + 0.001 \times 28 = 1.028$	$S_a = 1.028$
2.2.2.3	direction factor $S_d = 1$	$S_d = 1$

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTRo4
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	Feb 13

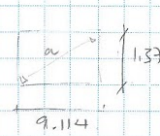
REFERENCE	CALCULATIONS	OUTPUT																				
2.2.2.4	seasonal factor S_s Poly tunnel will be exposed to wind > 6 months $S_s = 1$	$S_s = 1$																				
2.2.2.5	probability factor S_p take $S_p = 1$	$S_p = 1$																				
	$\therefore V_s = 23 \times 1.028 \times 1 \times 1 \times 1$ $= 23.6 \text{ m/s}$	$V_s = 23.6 \text{ m/s}$																				
2.2.3.1	effective wind speed V_e $V_e = V_s \times S_b$																					
2.2.3.3 Table 4	terrain and building factor S_b $H_e = 2.9 \text{ m}$ in town. closest distance to sea $= 50 \text{ km}$ <table><tr><td></td><td colspan="3">km</td></tr><tr><td>H_e</td><td>10</td><td>50</td><td>100</td></tr><tr><td>2</td><td>1.18</td><td>1.17</td><td>1.15</td></tr><tr><td>2.9</td><td></td><td><u>1.26</u></td><td></td></tr><tr><td>5</td><td>1.5</td><td>1.48</td><td>1.45</td></tr></table>		km			H_e	10	50	100	2	1.18	1.17	1.15	2.9		<u>1.26</u>		5	1.5	1.48	1.45	$S_b = 1.26$
	km																					
H_e	10	50	100																			
2	1.18	1.17	1.15																			
2.9		<u>1.26</u>																				
5	1.5	1.48	1.45																			
	$\therefore V_e = 23.6 \times 1.26 = 29.7 \text{ m/s}$	$V_e = 29.7 \text{ m/s}$																				

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Poly tunnel @ Roof	PTR 05
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	Feb 13

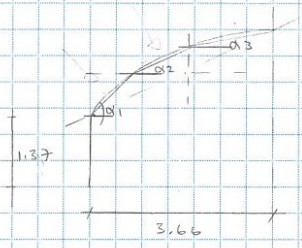
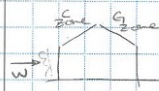
REFERENCE	CALCULATIONS	OUTPUT
2.1.2.1	<p>Dynamic Pressure $q_s = 0.613 V_e^2$</p> <p>$q_s = 0.613 \times 29.7^2$</p> <p>$= 540.7 \text{ Pa}^3$ $1 \text{ Pa} = 1 \text{ N/m}^2$</p> <p>$= 0.5 \text{ kN/m}^2$</p>	$q_s = 0.5 \text{ kN/m}^2$
2.1.3.1	<p>External surface pressure</p> <p>$p_e = q_s C_{pe} C_a$</p>	
Fig 4.	<p>Diagonal dimension $a =$</p> <p>$a = \sqrt{9.114^2 + 1.37^2}$</p> <p>$= 9.22 \text{ m}$ line C.</p> <p>$\therefore C_a = 0.94$</p>	
Table 5	External pressure coefficient C_{pe}	
Fig 12	<p>$B/D = 9.114 / 7.32 = 1.2$</p> <p>$D/H = 7.32 / 2.9 = 2.5$</p> <p>$\therefore C_{pe} = 0.725 \text{ (front)}$</p> <p>$= -0.5 \text{ (rear)}$</p>	
	<p>\therefore wind load on vertical wall</p> <p>① $= 0.5 \times 0.94 \times 0.725 = 0.34 \text{ kN/m}^2$</p> <p>② $= 0.5 \times 0.94 \times -0.5 = -0.235 \text{ kN/m}^2$</p>	<p>wind load on vertical wall</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTK05
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	Feb 13

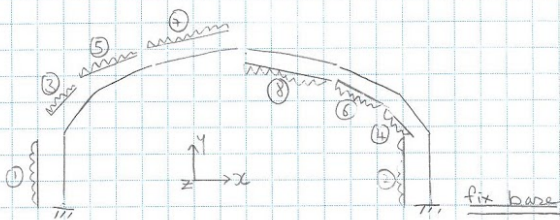
REFERENCE	CALCULATIONS	OUTPUT												
	<p>Pressure on curve roof. (multi pitch).</p>  <p>take $a = \sqrt{109.114^2 + 1.53^2}$ $= 9.24$ $C_a = 0.94$</p> <p>fastened curve in 3 parts</p> <p>$\alpha_1 = 57.4^\circ$ $\alpha_2 = 22.7^\circ$ $\alpha_3 = 6.4^\circ$</p> <p>Table 10 Cpe.</p> <table border="1"> <thead> <tr> <th>Zone</th> <th>W</th> <th>Zone G</th> </tr> </thead> <tbody> <tr> <td>for α_1</td> <td>$\rightarrow +0.8$</td> <td>-0.6</td> </tr> <tr> <td>α_2</td> <td>$\rightarrow +0.3$</td> <td>-0.5</td> </tr> <tr> <td>α_3</td> <td>$\rightarrow +0.1$</td> <td>-0.4</td> </tr> </tbody> </table>  <p>③ $p_e = 0.5 \times 0.8 \times 0.94 = 0.376 \text{ kN/m}^2$ ④ $= 0.5 \times -0.6 \times 0.94 = -0.282 \text{ kN/m}^2$ ⑤ $= 0.5 \times 0.3 \times 0.94 = 0.141 \text{ kN/m}^2$ ⑥ $= 0.5 \times -0.5 \times 0.94 = -0.235 \text{ kN/m}^2$ ⑦ $= 0.5 \times 0.1 \times 0.94 = 0.047 \text{ kN/m}^2$ ⑧ $= 0.5 \times -0.4 \times 0.94 = -0.188 \text{ kN/m}^2$</p>	Zone	W	Zone G	for α_1	$\rightarrow +0.8$	-0.6	α_2	$\rightarrow +0.3$	-0.5	α_3	$\rightarrow +0.1$	-0.4	
Zone	W	Zone G												
for α_1	$\rightarrow +0.8$	-0.6												
α_2	$\rightarrow +0.3$	-0.5												
α_3	$\rightarrow +0.1$	-0.4												

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PIR 07
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	Feb 13

REFERENCE	CALCULATIONS	OUTPUT
	<p>load width = 1.83m</p> <p>① = $0.34 \text{ kN/m}^2 \times 1.83 \text{ m} = 0.62 \text{ kN/m}$</p> <p>② = $-0.235 \text{ kN/m}^2 \times 1.83 \text{ m} = -0.43 \text{ kN/m}$</p> <p>③ = $0.376 \text{ kN/m}^2 \times 1.83 \text{ m} = 0.69 \text{ kN/m}$</p> <p>④ = $-0.282 \text{ kN/m}^2 \times 1.83 \text{ m} = -0.52 \text{ kN/m}$</p> <p>⑤ = $0.141 \text{ kN/m}^2 \times 1.83 \text{ m} = 0.26 \text{ kN/m}$</p> <p>⑥ = $-0.235 \text{ kN/m}^2 \times 1.83 \text{ m} = -0.43 \text{ kN/m}$</p> <p>⑦ = $0.047 \text{ kN/m}^2 \times 1.83 \text{ m} = 0.09 \text{ kN/m}$</p> <p>⑧ = $-0.188 \text{ kN/m}^2 \times 1.83 \text{ m} = -0.34 \text{ kN/m}$</p>	
		
	Apply loadings in STAAD model	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 08
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	Feb 13

REFERENCE	CALCULATIONS	OUTPUT
	<p>Apply Wind load reaction from Polytunnel to Beam 1 & Beam 2 & Beam 3</p> <p>STAAD result \Rightarrow wind only</p> <p> $X = -1.851 \text{ kN}$ $Y = 0.298 \text{ kN}$ $M_z = 1.884 \text{ kNm}$ </p> <p> $X = -0.987 \text{ kN}$ $Y = -0.899 \text{ kN}$ $M_z = 1.227 \text{ kNm}$ </p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER		
Irwell House			
ELEMENT	CALC SHEET NUMBER		
Polytunnel @ Roof	PTR 09		
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

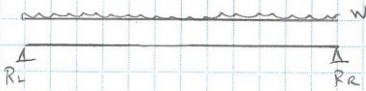
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Snow drift.</u></p> <p>Distance between polytunnel & building edge = 6m</p> <p>BS 6399,3 Fig. 6 Flowchart</p> <p>$h_0 = 1370 \text{ mm}$ $b_1 = 6000 \text{ mm}$</p> <p>$5h_0 = 6850 \text{ mm}$ $b_1 < 6850 \text{ mm}$ $\therefore b_1 = l_{s1} = 6000 \text{ mm}$</p> <p>$\frac{2h_0}{s_0} = \frac{2 \times 1.37}{0.6} = 4.6 < 8$ $> \frac{2b_1}{l_{s1}} = 2$</p> <p>$\therefore \mu_1 = \frac{2b_1}{l_{s1}} = 2$</p> <p>$S_d = \mu_1 \times S_0 = 2 \times 0.6 \text{ kN/m}^2 = 1.2 \text{ kN/m}^2$</p> <p>Since secondary beams got imposed load of 0.6 kN/m^2 applied already</p> <p>\therefore additional snow drift load = $1.2 \text{ kN/m}^2 - 0.6 \text{ kN/m}^2$ = 0.6 kN/m^2</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 10
DRAWING REF	

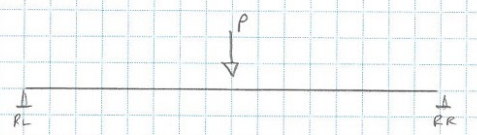
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Existing load on beams</u></p> <p>Secondary beam length = 6.1m load width = 4 m</p>  <p>Dead = 5 kN/m^2 $5 \times 4 = 20 \text{ kN/m}$</p> <p>Bending Moment = $\frac{wL^2}{8} = \frac{20 \times 6.1^2}{8} = 93 \text{ kNm}$</p> <p>Reaction = $\frac{wL}{2} = \frac{20 \times 6.1}{2} = 61 \text{ kN}$</p> <p>Imposed = 0.6 kN/m^2 $0.6 \times 4 = 2.4 \text{ kN/m}$</p> <p>Bending Moment = $\frac{wL^2}{8} = \frac{2.4 \times 6.1^2}{8} = 11.2 \text{ kNm}$</p> <p>Reaction = $\frac{wL}{2} = \frac{2.4 \times 6.1}{2} = 7.3 \text{ kN}$</p> <p>Total BM = 104.2 kNm V = 68.3 kN</p>	<p><u>Dead load</u> BM = 93 kNm V = 61 kN</p> <p><u>Imposed load</u> BM = 11.2 kNm V = 7.3 kN</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Poly tunnel @ Roof	PTR 11
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE
HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Existing load on beams:</u></p> <p>Primary beam length = 8m. Supports beams @ 4m</p>  <p>Dead point load = $61 \times 2 = 122 \text{ kN}$</p> <p>Bending Moment = $\frac{PL}{4} = \frac{122 \times 8}{4} = 244 \text{ kNm}$</p> <p>Reaction = $\frac{P}{2} = \frac{122}{2} = 61 \text{ kN}$</p> <p>Imposed point load = $7.3 \times 2 = 14.6 \text{ kN}$</p> <p>Bending Moment = $\frac{PL}{4} = \frac{14.6 \times 8}{4} = 29.2 \text{ kNm}$</p> <p>Reaction = $\frac{P}{2} = \frac{14.6}{2} = 7.3 \text{ kN}$</p> <p>Total BM = $244 + 29.2 = 273.2 \text{ kNm}$</p> <p>V = $61 + 7.3 = 68.3 \text{ kN}$</p>	<p><u>Dead load</u></p> <p>BM = 244 kNm</p> <p>V = 61 kN</p> <p><u>Imposed load</u></p> <p>BM = 29.2 kNm</p> <p>V = 7.3 kN</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 12
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

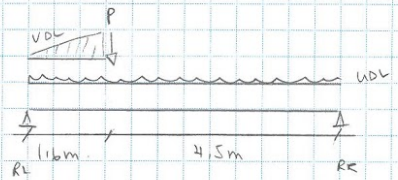
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Existing load on beam:</u></p> <p><u>Secondary beam</u> length = 4m. loadwidth = 4m.</p> <p>Dead = 20 kN/m.</p> <p>Bending moment = $20 \times 4^2 / 8 = 40 \text{ kNm}$</p> <p>Reaction = $20 \times 4 / 2 = 40 \text{ kN}$.</p> <p>Imposed = 2.4 kN/m</p> <p>Bending moment = $2.4 \times 4^2 / 8 = 4.8 \text{ kNm}$</p> <p>Reaction = $2.4 \times 4 / 2 = 4.8 \text{ kN}$.</p> <p>Total BM = $40 + 4.8 = 44.8 \text{ kNm}$.</p> <p>V = $40 + 4.8 = 44.8 \text{ kN}$.</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 13
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

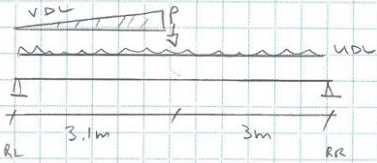
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams.</u></p> <p>Secondary beam <u>Beam B1</u></p> <p>Beam length = 6.1 m.</p> <p>load width of polytunnel = 2.1 m</p>  <p>\therefore load support area = $2.1 \times 7.315 / 2$ = 7.7 m^2</p> <p>Dead = $5 \text{ kN/m}^2 \times 4 \text{ m} = 20 \text{ kN/m}$ $G_k = 20 \text{ kN/m}$</p> <p>Live = $0.6 \text{ kN/m}^2 \times 4 \text{ m} = 2.4 \text{ kN/m}$ $Q_k = 2.4 \text{ kN/m}$</p> <p>Polytunnel point load = $0.1 \text{ kN/m}^2 \times 7.7 \text{ m}^2$ = 0.8 kN $Q_{kp} = 0.8 \text{ kN}$</p> <p>wind point load (1.2 hoops proportion) = $X = -1.9 \times 1.2 = -2.3 \text{ kN}$ $Y = 0.3 \times 1.2 = 0.36 \text{ kN}$ $M_z = 1.9 \times 1.2 = 2.3 \text{ kNm}$</p> <p>snow drift VDL = $0.6 \text{ kN/m}^2 \times 2$ = 1.2 kN/m $Q_{ks} = 1.2 \text{ kN/m}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 14
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

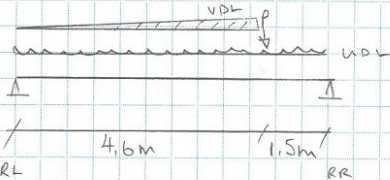
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams</u></p> <p>Secondary beam <u>Beam B2</u></p> <p>Beam length = 6.1m</p> <p>Load width of polytunnel = 4.3m</p>  <p>∴ load support area = $4.3 \times 7.315 / 2$ = 15.7 m^2</p> <p>Dead UDL = 20 kN/m GK = 20 kN/m</p> <p>Live UDL = 2.4 kN/m QK = 2.4 kN/m</p> <p>Polytunnel point load = $0.1 \text{ kN/m}^2 \times 15.7 \text{ m}^2$ = 1.6 kN QKp = 1.6 kN</p> <p>Wind point load (2.4 hoops) = X = -1.9×2.4 = -4.6 kN Y = 0.3×2.4 = 0.7 kN Mz = -1.9×2.4 = -4.6 kNm</p> <p>Snow drift vdl = $0.6 \text{ kN/m}^2 \times 4$ = 2.4 kN/m QKs = 2.4 kN/m</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 15
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

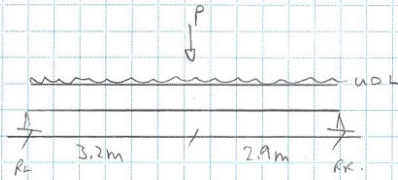
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams</u></p> <p>Secondary beam <u>Beam B3</u></p> <p>Beam length = 6.1 m</p> <p>Load width of polytunnel = 4.3 m</p>  <p>loads same as Beam B2</p> <p>Dead = 20 kN/m</p> <p>Live = 2.4 kN/m</p> <p>Polytunnel = 1.6 kN</p> <p>wind = x = -4.6 kN (horizontal) y = +0.7 kN (vertical) M_z = +4.6</p> <p>snow drift = 2.4 kN/m</p>	<p>GK = 20 kN/m</p> <p>QK = 2.4 kN/m</p> <p>QKP = 1.6 kN</p> <p>QKw</p> <p>QKs = 2.4 kN/m</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 16
DRAWING REF	

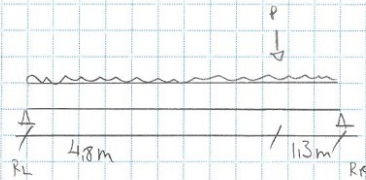
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams</u></p> <p>Secondary beam <u>Beam B4</u></p> <p>Beam length = 6.1 m.</p> <p>Load width of polytunnel. = 4.8 m.</p>  <p>\therefore load support area = $4.8 \times 7.35 / 2$ = 17.6 m^2</p> <p>Dead UDL = 20 kN/m</p> <p>Live UDL = 2.4 kN/m</p> <p>Polytunnel point load = $0.1 \text{ kN/m}^2 \times 17.6 \text{ m}^2$ = 1.8 kN</p> <p>wind point load (2.6 hoops)</p> <p>$X = -1.9 \times 2.6 = -5 \text{ kN}$</p> <p>$Y = +0.3 \times 2.6 = +0.8 \text{ kN}$</p> <p>$M_z = +1.9 \times 2.6 = +5 \text{ kNm}$</p>	<p>$GK = 20 \text{ kN/m}$</p> <p>$QK = 2.4 \text{ kN/m}$</p> <p>$QKp = 1.8 \text{ kN}$</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel C Roof	PTR 17
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE
HL	March 13

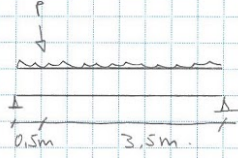
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams:</u></p> <p>Secondary beam <u>Beam B5</u></p> <p>Beam length = 6.1 m</p> <p>Load width of polytunnel = 4.3 m.</p>  <p>Loads same as Beam B2</p> <p>Dead = 20 k/m</p> <p>Live = 2.4 k/m</p> <p>Polytunnel = 1.6 kN</p> <p>wind = x = -4.6 k (horizontal) y = +0.7 k (vertical) M_z = +4.6 kNm</p>	<p>GK = 20 k/m</p> <p>QK = 2.4 k/m</p> <p>QKp = 1.6 kN.</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PR 18
DRAWING REF	

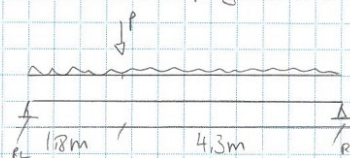
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams</u></p> <p>Secondary beam Beam B6</p> <p>Beam length = 4m</p> <p>Load width of polytunnel = 4.3m</p>  <p>Load Same as Beam B2</p> <p>Dead = 20 kN/m</p> <p>Live = 2.4 kN/m</p> <p>Polytunnel = 1.6 kN</p> <p>wind = $x = -4.6 \text{ kN}$ (horizontal) $y = +0.7 \text{ kN}$ (vertical) $M_z = +4.6 \text{ kNm}$</p>	
		<p>$G_k = 20 \text{ kN/m}$</p> <p>$Q_k = 2.4 \text{ kN/m}$</p> <p>$Q_{kp} = 1.6 \text{ kN}$</p>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 19
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE
HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams</u></p> <p>Secondary beam <u>Beam B7</u></p> <p>Beam length = 6.1 m.</p> <p>load width of polytunnel = 1.6 m</p>  <p>\therefore load support area = $\frac{1.6 \times 7.315}{2}$ = 5.9 m^2</p> <p>Dead = 20 kN/m</p> <p>Live = 2.4 kN/m</p> <p>Polytunnel point load = $0.1 \text{ kN/m}^2 \times 5.9 \text{ m}^2$ = 0.6 kN</p> <p>wind point load (0.9 hoop) = $X = -1.9 \times 0.9 = -1.7 \text{ kN}$ $Y = +0.3 \times 0.9 = +0.27 \text{ kN}$ $M_z = +1.9 \times 0.9 = +1.7 \text{ kNm}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
<u>Irwell House</u>	
ELEMENT	CALC SHEET NUMBER
<u>Polytunnel @ Roof</u>	<u>PTR 20</u>
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		<u>HL</u>	<u>March 13</u>

REFERENCE	CALCULATIONS	OUTPUT
<u>STAAD</u> <u>Analysis</u>	<u>Bending Moment & Reactions with total loads</u>	Compare with Existing
	<u>Beam B1</u>	BM = <u>104.2 kNm</u> V = <u>68.3 kN</u>
	<u>Bending Moment</u> = <u>107 kNm</u>	+ 2.7%
	<u>Reaction left</u> = X = <u>-1.7 kN</u> (horizontal) Y = <u>69.6 kN</u> (vertical)	+ 1.9%
	<u>Reaction right</u> = X = <u>-0.603 kN</u> (horizontal) Y = <u>69.2 kN</u> (vertical)	+ 1.3%
	<u>Beam B2</u>	
	<u>Bending Moment</u> = <u>114 kNm</u>	+ 9.4%
	<u>Reaction left</u> = X = <u>-7.3 kN</u> (horizontal) Y = <u>71.2 kN</u> (vertical)	+ 4.2%
	<u>Reaction right</u> = X = <u>-2.3 kN</u> (horizontal) Y = <u>71.5 kN</u> (vertical)	+ 4.7%
	<u>Beam B3</u>	
	<u>Bending Moment</u> = <u>116 kNm</u>	+ 5.6%
	<u>Reaction left</u> = X = <u>-1.13 kN</u> (horizontal) Y = <u>70.9 kN</u> (vertical)	+ 3.8%
	<u>Reaction right</u> = X = <u>-3.5 kN</u> (horizontal) Y = <u>78.6 kN</u> (vertical)	+ 7.8%

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel Roof	PTR 21
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
STAAD Analysis	<u>Bending Moment + Reactions with total loads:</u>	Compare with Existing
	<u>Beam B4</u>	BM = 104.2 kNm V = 68.3 kN
	<u>Bending Moment</u> = 110 kNm	+ 5.6 %
	<u>Reaction left</u> = x = -2.4 kN (horizontal) y = 68.7 kN (vertical)	+ 0.6 %
	<u>Reaction right</u> = x = -2.6 kN (horizontal) y = 70.5 kN (vertical)	+ 3.2 %
	<u>Beam B5</u>	
	<u>Bending Moment</u> = 103 kNm	- 1.2 %
	<u>Reaction left</u> = x = -1 kN (horizontal) y = 68.1 kN (vertical)	- 0.3 %
	<u>Reaction right</u> = x = -3.6 kN (horizontal) y = 70.9 kN (vertical)	+ 3.8 %
	<u>Beam B6</u>	Compare with Existing BM = 44.8 kNm V = 44.8 kN
	<u>Bending Moment</u> = 47.7 kNm	+ 6.5 %
	<u>Reaction left</u> = x = -4 kN (horizontal) y = 45.4 kN (vertical)	+ 1.8 %
	<u>Reaction right</u> = x = -0.6 kN (horizontal) y = 46.2 kN (vertical)	+ 3.1 %

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR 22
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

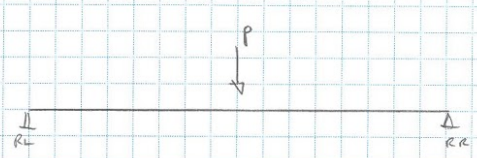
REFERENCE	CALCULATIONS	OUTPUT
	<u>Bending Moment + Reactions with total loads:</u>	Compare with Existing
	<u>Beam 7</u>	BM = 16.42 kNm V = 68.3 kN
	Bending Moment = 106 kNm	+ 1.7 %
	<u>Reactions left</u> =	x = -1.2 kN (horizontal) y = 69 kN (vertical)
		+ 1 %
	<u>Reactions right</u> =	x = -0.5 kN (horizontal) y = 69 kN (vertical)
		+ 1 %

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Inwell House	
ELEMENT	CALC SHEET NUMBER
Poly tunnel @ Roof	PTR 23
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

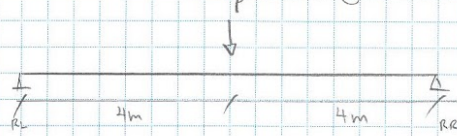

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams.</u></p> <p>Primary beam <u>Beam B8.</u></p> <p>Beam length = 8m.</p> <p>point load @ 4m , B2 & B5 reactions.</p>  <p> $P = B2 R_L + B5 R_L$ $= 71.5 + 68.1 = 139.6 \text{ kN}$ </p> <p><u>Bending Moment</u></p> <p> $= \frac{PL}{4} = \frac{139.6 \times 8}{4} = 279.2 \text{ kNm}$ </p> <p><u>Reactions.</u></p> <p> $= P/2 = 139.6 / 2 = 69.8 \text{ kN}$ </p> <p>Compare with existing. $BM = 273.2 \text{ kNm}$ $V = 68.3 \text{ kN}$</p> <p>BM increase +2.2 %</p> <p>V increase +2.2 %</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR24
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

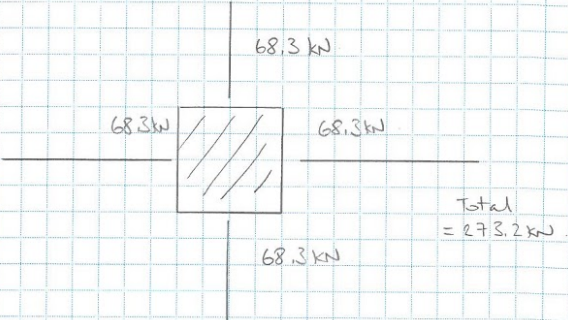
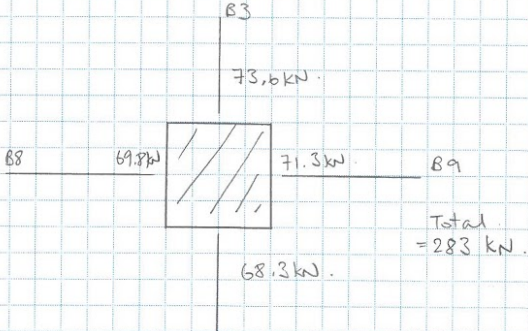
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams</u></p> <p>Primary beam <u>Beam B9</u></p> <p>Beam length = 8m.</p> <p>point load @ 4m.</p> <p>Existing Secondary beam reaction of Polytunnel.</p>  <p>Secondary beam reaction = Dead + Imposed $= 61 + 7.3 = 68.3 \text{ kN} \times 2 = 136.6 \text{ kN}.$</p> <p>Beam B9a snowdrift reaction \rightarrow</p>  <p>$\text{VOL} = 0.6 \times 4 = 2.4 \text{ kN/m}.$ $R_R = (2.4 \times 6) / 2 \times 2/3 = 4.8 \text{ kN}.$</p> <p>Polytunnel. load width = 4.3m.</p> <p>\therefore point load = 1.6 kN</p> <p>wind pointload = $x = -4.6 \text{ kN}$ $y = +0.7 \text{ kN}.$ $M_x = -4.6 \text{ kNm}.$</p>	<p><u>Summary</u></p> <p>All beams are within 10% allowable increase</p>
STAAD analysis	<p><u>Bending moment</u> = 290 kNm.</p> <p><u>Reaction left</u> = $x = -2.3 \text{ kN}$ (horizontal) $y = 71.3$ (vertical)</p> <p><u>Reaction right</u> = $x = -2.3 \text{ kN}$ (horizontal) $y = 72.4$ (vertical)</p>	<p>Compare with Existing.</p> <p>BM = 273.2 kNm</p> <p>V = 68.3 kN.</p> <p>+ 6.1%</p> <p>+ 4.4%</p> <p>+ 6%</p>

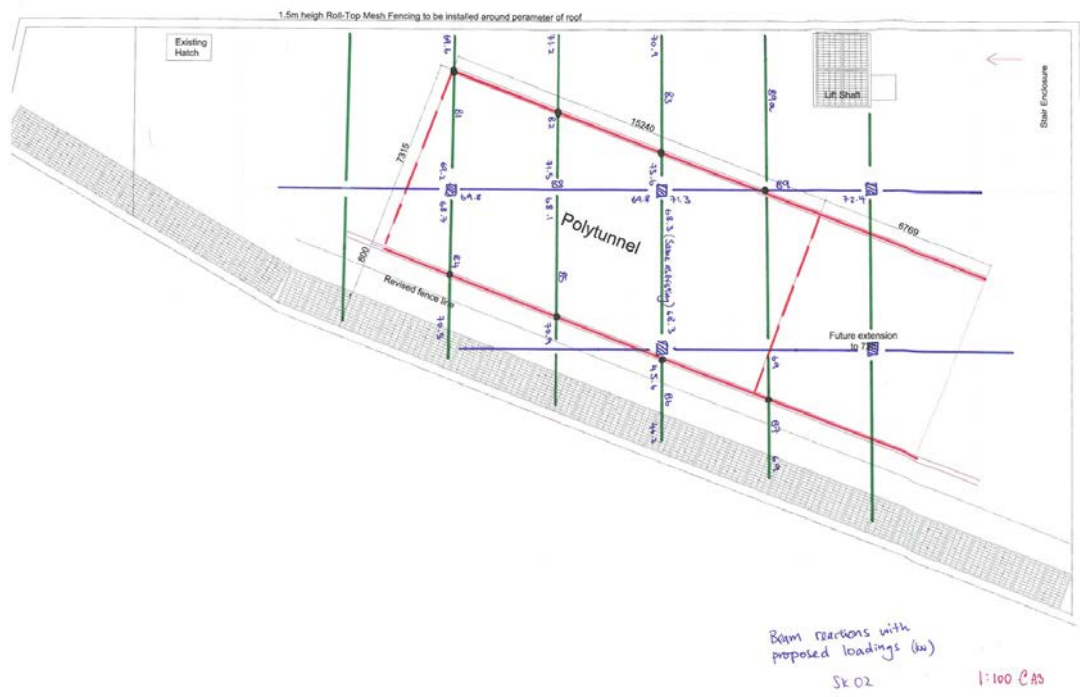
Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR25
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p>Existing load on column. C1</p>  <p>68.3 kN</p> <p>68.3 kN</p> <p>68.3 kN</p> <p>68.3 kN</p> <p>Total = 273.2 kN.</p>	
	 <p>B3</p> <p>73.6 kN</p> <p>68.3 kN</p> <p>69.4 kN</p> <p>71.3 kN</p> <p>Total = 283 kN.</p>	



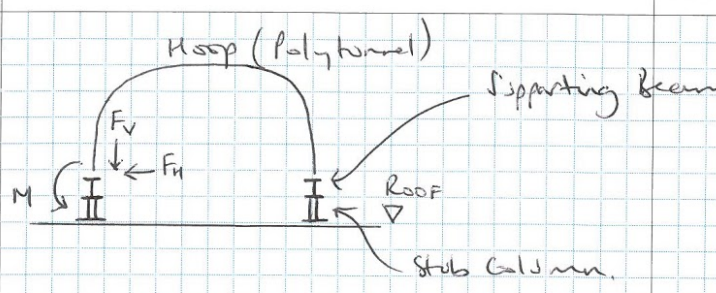
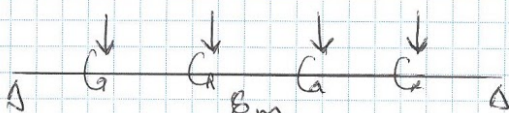
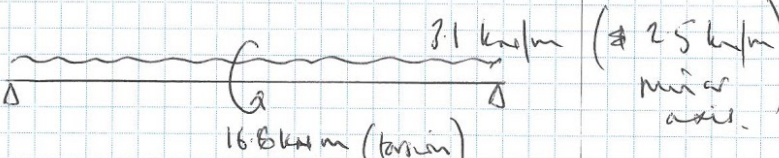
3.0 Polytunnel Supporting Beam

To only allow the polytunnel to be supported by the secondary beams, supporting beams are designed to transfer the polytunnel loading as point loads onto the secondary beams.

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER		
Ipsell House			
ELEMENT	CALC SHEET NUMBER		
Polytunnel Supporting beam	PTB 01		
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		JP	March 13

REFERENCE	CALCULATIONS	OUTPUT
	 <p>Worse case loading from dead and imposed load (snow load)</p> $F_v = 6.1 \text{ kN per hoop} \times 4/8 = 3.1 \text{ kN/m}$ $F_h = 4.9 \text{ kN per hoop} \times 4/8 = 2.5 \text{ kN/m}$ $M = 4.2 \text{ kNm} \times 4 = 16.8 \text{ kNm (torque)}$  <p>Equivalent UDL</p> 	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel Supporting Beam	PTB 02
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JP	March 13

REFERENCE	CALCULATIONS	OUTPUT
	$M_x = 3.1 \cdot 8^2 / 8 = 24.8 \text{ kNm}$ $M_y = 2.8 \cdot 8^2 / 8 = 22.4 \text{ kNm}$ $\text{Max Shear} = 3.1 \times 2 = 6.2 \text{ kN}$	


Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel Supporting Beam	PTB 03
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JP	March 13

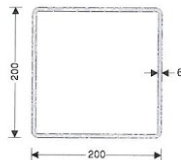
REFERENCE	CALCULATIONS	OUTPUT
	<p>Check Deflection.</p> <p>Assumed size 200 x 200 x 6 S.W.F.</p> $\delta = \frac{5}{384} \cdot \frac{(3.1 / 1.4) 8.0^4}{205 \times 10^6 \cdot 2410 \times 10^{-8}} \times 10^3$ <p>= 24 mm. OK ✓</p>	

 Tedds BDP 11 Ducie Street Manchester	Project <i>Irwell House</i>		Job no.	
	Calcs for <i>Polytunnel Supporting Beam</i>		Start page no./Revision <i>PTB04</i>	
	Calcs by <i>J</i>	Calcs date <i>08/03/2013</i>	Checked by	Checked date
				Approved date

STEEL BEAM TORSION DESIGN

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

Tedds calculation version 2.0.01



Section details

Section type	SHS 200x200x6.0
Steel grade	S355
Design strength	$p_{yw} = p_y = 355 \text{ N/mm}^2$
Constant	$\epsilon = \sqrt{(275 \text{ N/mm}^2 / p_y)} = 0.880$

Calculated torsional properties

Height of web	$d_x = b_y = D - 3 \times t = 182.0 \text{ mm}$
Width of flange	$b_x = d_y = B - 3 \times t = 182.0 \text{ mm}$
Shear area - y	$A_{vy} = A \times D / (D + B) = 23.1 \text{ cm}^2$
Shear area - x	$A_{vx} = A \times B / (D + B) = 23.1 \text{ cm}^2$
	$d_{vx} = A_{vx} / (2 \times t) = 192.4 \text{ mm}$
	$d_{vy} = A_{vy} / (2 \times t) = 192.4 \text{ mm}$
Plastic modulus of web	$S_{wx} = 2 \times t \times d_{vy}^2 / 4 = 111.0 \text{ cm}^3$
Plastic modulus of flange	$S_{wy} = 2 \times t \times d_{vx}^2 / 4 = 111.0 \text{ cm}^3$
Statical moment at mid-depth of section	$Q_w = S_x / 2 = 167 \text{ cm}^3$

Geometry - Beam unrestrained against lateral-torsional buckling between supports.

Effective span	$L = 8000 \text{ mm}$
Length of segment for LT buckling	$L_{LT} = 8000 \text{ mm}$
Compression flanges laterally unrestrained	
Partial torsional restraint against rotation about longitudinal axis provided by connection of bottom flange to supports	
Effective length for LT buckling	$L_{E,LT} = L_{LT} \times 1.2 + 2 \times D = 10000 \text{ mm}$

Loading - Torsional loading comprises only full-length uniformly distributed load(s)

Internal forces & moments on member under factored loading for ult design


Applied shear force	$F_{vy} = 6.2 \text{ kN}$
Maximum bending moment	$M_{LT} = M_k = 24.80 \text{ kNm}$
Applied torque	$T_q = 16.80 \text{ kNm}$
Minor axis bending moment	$M_y = 0 \text{ kNm}$
Compression force	$F_c = 0 \text{ kN}$

Equivalent uniform moment factors

EUM factor (Cl. 4.3.6.6 and T18)	$m_{LT} = 1.000$
----------------------------------	------------------

Torsional deflection analysis

Beam is torsion fixed at each end. (as defined in SCI-P-057 section 2.1.6)	
Maximum torque (at supports)	$T_o = T_q / 2 = 8.40 \text{ kNm}$

 Tedds BDP 11 Ducie Street Manchester	Project <i>Irwell House</i>		Job no.	
	Calcs for <i>Polytunnel Supporting Beam</i>		Start page no./Revision <i>PTBDS 2</i>	
	Calcs by <i>J</i>	Calcs date <i>08/03/2013</i>	Checked by	Checked date
			Approved by	Approved date

Average torque between support & centreline

$$T_{av} = T_o / 2 = 4.20 \text{ kNm}$$

Max. angle of twist (at midspan)

$$\phi = T_{av} / (G \times J) \times L / 2 \times 1 \text{ rads} = 0.005 \text{ rads}$$

Section classification

$$b_x / t = 30.3$$

$$d_x / t = 30.3$$

$$b_y / t = 30.3$$

$$d_y / t = 30.3$$

$$r_{1sx} = \min(1.0, \max(-1.0, F_c / (2 \times d_x \times t \times p_{yw}))) = 0.000$$

$$r_{1sy} = \min(1.0, \max(-1.0, F_c / (2 \times d_y \times t \times p_{yw}))) = 0.000$$

$$r_{2s} = F_c / (A_g \times p_{yw}) = 0.000$$

Section classification is semi-compact

Shear capacity (parallel to y-axis)

Design shear force

$$F_{vy} = 6.2 \text{ kN}$$

Design shear resistance (Cl. 4.2.3)

$$P_{vy} = 0.6 \times p_y \times A_{vy} = 491.8 \text{ kN}$$

Pass - Shear

Moment capacity (x-axis)

Design bending moment

$$M_x = 24.8 \text{ kNm}$$

Moment capacity

$$M_{cxu} = p_y \times Z_x = 102.4 \text{ kNm}$$

Moment capacity low shear (Cl. 4.2.5.1)

$$M_{cx} = \min(p_y \times Z_x, 1.2 \times p_y \times Z_x) = 102.4 \text{ kNm}$$

Pass - Moment capacity exceeds design bending moment

Lateral torsional buckling

LT buckling check not required for this section (cl. 4.6.3.1)

Buckling resistance moment

$$M_b = M_{cx} = 102.4 \text{ kNm}$$

LT buckling check not required for this section

Buckling under combined bending & torsion - SCI-P-057 section 2.3

For simplicity, a conservative check is applied using the maximum stresses due to each of the separate load effects, even though these do not necessarily all occur at the same section along the member.

Maximum angle of twist

$$\phi = 0.005 \text{ rads}$$

Induced minor axis moment

$$M_{yt} = M_x \times \phi / 1 \text{ rad} = 0.12 \text{ kNm}$$

Normal stress at corner due to M_{yt}

$$\sigma_{byt} = M_{yt} / Z_y = 0 \text{ N/mm}^2$$

Interaction index

$$i_b = M_x \times m_{LT} / M_b + \sigma_{byt} / p_y \times (1 + 0.5 \times M_x \times m_{LT} / M_b) = 0.24$$

Pass - Combined bending and torsion check satisfied

Local capacity under combined bending & torsion

For simplicity, a conservative check is applied using the maximum stresses due to each of the separate load effects, even though these do not necessarily all occur at the same section along the member.

Max. direct stress due to M_x

$$\sigma_{bx} = M_x / Z_x = 86 \text{ N/mm}^2$$

Combined stress - eqn 2.22

$$\sigma_{bx} + \sigma_{byt} = 86 \text{ N/mm}^2$$

Design strength

$$p_y = 355 \text{ N/mm}^2$$

Pass - Local capacity

Combined shear stresses SCI-P-057 section 2.3

For simplicity, a conservative check is applied using the maximum shear stresses due to each of the separate load effects, even though these do not necessarily all occur at the same section along the member.

Max. shear stress due to bending

$$\tau_{bw} = F_{vy} \times Q_w / (I_x \times 2 \times t) = 3 \text{ N/mm}^2$$

Max. shear stresses due to torsion

$$\tau_t = T_o / C = 20 \text{ N/mm}^2$$

Amplified shear stress due to torsion

$$\tau_{vt} = \tau_t \times (1 + 0.5 \times M_x \times m_{LT} / M_b) = 22 \text{ N/mm}^2$$

 Tedds BDP 11 Ducie Street Manchester	Project <i>Irwell House</i>				Job no.	
	Calcs for <i>Polytunnel Supporting Beam</i>				Start page no./Revision <i>PTB 06 6</i>	
	Calcs by <i>J</i>	Calcs date <i>08/03/2013</i>	Checked by	Checked date	Approved by	Approved date

Combined shear due to bending & torsion

$$\tau = \tau_{bw} + \tau_{vt} = 25 \text{ N/mm}^2$$

Shear strength

$$p_v = 0.6 \times p_y = 213 \text{ N/mm}^2$$

Pass - Combined shear stresses

Twist check

Total applied torque (unfactored)

$$T_{qu} = 12.00 \text{ kNm}$$

Maximum twist under sls loading

$$\phi_{sls} = \phi \times T_{qu} / T_q = 0.20 \text{ deg}$$

Twist limit

$$\phi_{lim} = 2.50 \text{ deg}$$

Pass - Twist

Deflection

Maximum y-axis deflection (from earlier calcs)

$$\delta_{y_max} = 24.0 \text{ mm}$$

Deflection limit - cl. 2.5.2

$$\delta_{lim} = \min(L / k_s, \delta_{lim_abs}) = 32.0 \text{ mm}$$

Pass - Deflection within specified limit

4.0 Second Floor Loading

Same beam loading capacity assessment approach as for roof level.

For the existing imposed load, we allowed for 50kg/sq.ft (2.4KN/m²) according to BS449 1984 Table 5.6, as it is the minimum non domestic occupancy allowance.

For the proposed imposed floor load, we proposed to have an allowance of 1.5KN/m². Taking an average person weight of 80kg, this would allow 45 people in one bay (4m x 6m) at one time.

During the preparation of this calculation package, the beam to column connection has been exposed for inspection. It was a simple angle cleat connection and it was not possible to prove the connection was within loading capacity for the existing load. Therefore we propose to install a 10mm thick stiffness plate to the angle cleat to increase its connection capacity.

Table 5.6 Imposed loads from BS449 1948

Class of loading	Floor space occupancy	Superimposed floor load per sq.ft.	Minimum* loads on slabs or floor boards per ft. width, uniformly distributed	Minimum* load on beams uniformly distributed
I	Private dwellings of not more than two storeys	30	240	1920
II	Rooms in private dwellings of more than two storeys, including flats; hospital rooms and wards; bedrooms and private sitting rooms in hotels and tenement houses; and similar occupancies	40	320	2560
III	Rooms used as offices	50	400	3200
IV	Classrooms in schools and colleges; minimum for light workshops	60	480	3840
V	Banking halls and offices where the public may congregate	70	560	4480
VI	Retail shops; places of assembly with fixed seating†; churches and chapels; restaurants; garages for vehicles not exceeding 2½ tons gross weight (private cars, light vans, etc.); circulation space in machinery halls, power stations, pumping stations etc., where not occupied by plant or equipment	80	640	5120
VII	Places of assembly without fixed seating (public rooms in hotels, dance halls, etc.); minimum for filing or record rooms in offices; light, workshops generally, including light machinery	100	800	6400
VIII	Garages to take all types of vehicles	100	Worst combination of actual wheel loads or, if the slab is capable of effective lateral distribution of load, 1.5 x maximum wheel load, but not less than 2000 lb, considered to be distributed over a floor area 2 ft.6 in. square.	
IX	Light storage space in commercial and industrial buildings; medium workshops	150	—	—
X	Minimum for warehouses and general storage space in commercial and industrial buildings; heavy workshops. (The loads imposed by heavy plant and machinery should be determined and allowed for.)	200	—	—

* Minimum load for slabs becomes operative at spans of less than 8 ft. Minimum load for beams becomes operative on areas less than 64 sq. ft. Beams, ribs and joists spaced at not more than 3 ft. centres may be calculated for slab loadings.

The loadings stated in these columns refer to the design of the slabs and individual beams respectively, including their connections.

† Fixed seating implies that the removal of the seating and the use of the space for other purposes are improbable.

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading.	SFL 01
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
BS449 1948 Table 5.6 Class III	<u>Beam B1</u>	
	beam length = 6m. load width = 4m	
	<u>Existing load</u>	
	Dead = 5 kN/m^2 $5 \times 4 = 20 \text{ kN/m}$	
	Imposed = 2.4 kN/m^2 $2.4 \times 4 = 9.6 \text{ kN/m}$	
	<u>Bending Moment</u>	
	$M = \frac{wl^2}{8} = \frac{(20+9.6) \times 6^2}{8} = 133.2 \text{ kNm}$	$M = 133.2 \text{ kNm}$
	<u>Beam Reaction</u>	
	$V = \frac{wl}{2} = \frac{29.6 \times 6}{2} = 88.8 \text{ kN}$	$V = 88.8 \text{ kN}$
	<u>Proposed load</u>	
	Dead = 5 kN/m^2 $5 \times 4 = 20 \text{ kN/m}$	
	Imposed = 1.5 kN/m^2 $1.5 \times 4 = 6 \text{ kN/m}$	
	Add. wL = 5.6 kN/m	
	<u>Bending Moment</u>	
	$M = \frac{wl^2}{8} = \frac{(20+6+5.6) \times 6^2}{8} = 142.2 \text{ kNm}$	$M = 142.2 \text{ kNm}$
	<u>Beam Reaction</u>	
	$V = \frac{wl}{2} = \frac{31.6 \times 6}{2} = 94.8 \text{ kN}$	$V = 94.8 \text{ kN}$

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second floor Loading	SFL 02
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Beam B2</u></p> <p>beam length = 6m load width = 4m</p> <p><u>Existing load</u></p> <p>Same as B1 $\therefore M = 133.2 \text{ kNm}$ $M = 133.2 \text{ kNm}$</p> <p>$V = 88.8 \text{ kN}$ $V = 88.8 \text{ kN}$</p>	
	<p><u>Proposed load</u></p> <p>Dead = $5 \text{ kN/m}^2 \times 4 \text{ m} = 20 \text{ kN/m}$</p> <p>Imposed = $1.5 \text{ kN/m}^2 \times 4 \text{ m} = 6 \text{ kN/m}$</p> <p><u>Bending moment</u></p> <p>$BM = \frac{wl^2}{8} = \frac{26 \times 6^2}{8} = 117 \text{ kNm}$ $M = 117 \text{ kNm}$</p> <p><u>Beam reaction</u></p> <p>$V = \frac{wl}{2} = \frac{26 \times 6}{2} = 78 \text{ kN}$ $V = 78 \text{ kN}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading	SFL 03
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Beam B3</u></p> <p>Beam length = 8m Supports B2 @ 4m</p> <p>Existing load</p> <p>Dead = $5 \text{ kN/m}^2 \times 4 \text{ m} \times 6 \text{ m} = 120 \text{ kN}$</p> <p>Imposed = $2.4 \text{ kN/m}^2 \times 4 \text{ m} \times 6 \text{ m} = 57.6 \text{ kN}$</p> <p>Bending moment</p> <p>$BM = \frac{Pl}{4} = \frac{(120 + 57.6) \times 8}{4} = 355.2 \text{ kNm}$ $M = 355.2 \text{ kNm}$</p> <p>Beam Reaction</p> <p>$V = P/2 = (120 + 57.6)/2 = 88.8 \text{ kN}$ $V = 88.8 \text{ kN}$</p>	
	<p><u>Proposed load</u></p> <p>Dead = 120 kN @ 4m</p> <p>Imposed = $1.5 \text{ kN/m}^2 \times 4 \text{ m} \times 6 \text{ m} = 36 \text{ kN @ 4m}$</p> <p>Add. udl = say 34.5 kN / 5.6m = 6.2 kN/m @ 0.9m → 6.5m</p> <p>Bending moment</p> <p>TEDDS - $BM = 356.9 \text{ kNm}$ $M = 356.9 \text{ kNm}$</p> <p>Beam reaction</p> <p>$V = \begin{matrix} R_L = 96.7 \text{ kN} \\ R_R = 94.1 \text{ kN} \end{matrix}$ $V = \begin{matrix} 96.7 \text{ kN} \\ 94.1 \text{ kN} \end{matrix}$</p>	

15.15

BDP.

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Beam B4</u></p> <p>beam length = 6m load width = 4m.</p> <p>Existing load</p> <p>same as B1 $\therefore M = 133.2 \text{ kNm}$ $M = 133.2 \text{ kNm}$</p> <p>$V = 88.8 \text{ kN}$ $V = 88.8 \text{ kN}$</p>	
	<p>Proposed load</p> <p>Dead = 20 kN/m</p> <p>Imposed = 6 kN/m.</p> <p>Add P = 7.5 kN @ 3m.</p> <p>Bending moment</p> <p>$BM = \frac{wl^2}{8} + \frac{Pl}{4} = \frac{26 \times 6^2}{8} + \frac{7.5 \times 6}{4} = 128.25 \text{ kNm}$ $M = 128.25 \text{ kNm}$</p> <p>Beam reaction</p> <p>$V = \frac{wl}{2} + \frac{P}{2} = \frac{26 \times 6}{2} + \frac{7.5}{2} = 81.75 \text{ kN}$ $V = 81.75 \text{ kN}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second floor Loading	SFL 05
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

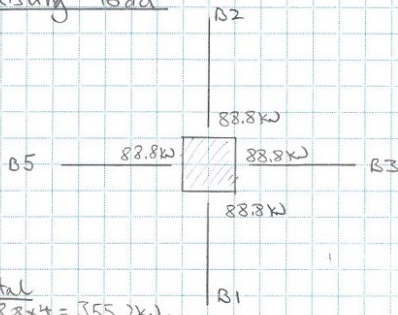
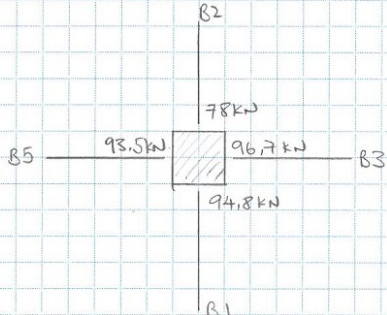
REFERENCE	CALCULATIONS	OUTPUT
	<u>Beam B5</u> beam length = 8m Supports B+C @ 4m. Existing load same as B3 ∴ $M = 355.2 \text{ kNm}$ $V = 88.8 \text{ kN}$	$M = 355.2 \text{ kNm}$ $V = 88.8 \text{ kN}$
	<u>Proposed load</u> Dead = 120 kN @ 4m Imposed = 36 kN @ 4m Add. P = 7.5 kN/2 @ 4m. Add. wDL = 3.4 kN/m	
	<u>Bending moment</u> $BM = \frac{Pl}{4} + \frac{wl^2}{8} = \frac{(120+36+3.75) \times 8}{4} + \frac{3.4 \times 8^2}{8}$ $= 319.5 + 27.2 = 346.7 \text{ kNm}$	$M = 346.7 \text{ kNm}$
	<u>Beam reaction</u> $V = \frac{Pl}{2} + \frac{wl}{2} = \frac{(120+36+3.75)}{2} + \frac{3.4 \times 8}{2} = 93.5 \text{ kN}$	$V = 93.5 \text{ kN}$

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading	SFL 06
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Column C1</u></p> <p><u>Existing load</u></p>  <p>total $88.8 \times 4 = 355.2 \text{ kN}$</p> <p><u>Proposed load</u></p>  <p>total $78 + 96.7 + 94.8 + 93.5$ $= 363 \text{ kN}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading	SFL07
DRAWING REF	

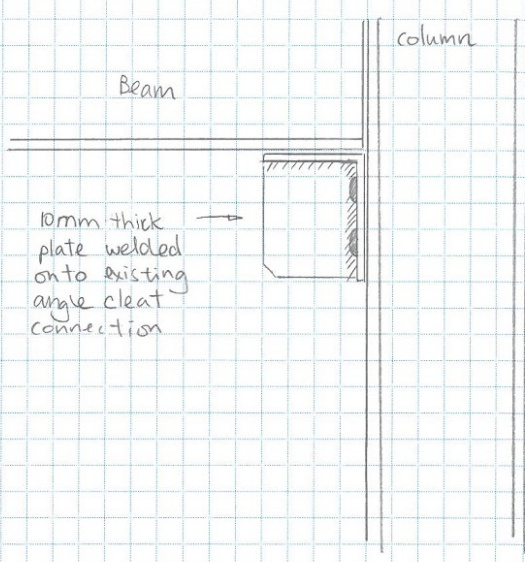
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS				OUTPUT
<u>Summary Existing load VS Propose load</u>					
		Existing	Propose	Difference	
Beam B1	BM	133.2 kNm	142.2 kNm	+6.8%	
	V	88.8 kN	94.8 kN	+6.8%	
Beam B2	BM	133.2 kNm	117 kNm	-12.2%	
	V	88.8 kN	78 kN	-12.2%	
Beam B3	BM	355.2 kNm	356.9 kNm	+0.5%	
	V	88.8 kN	96.7 kN	+8.9%	
Beam B4	BM	133.2 kNm	128.25 kNm	-3.7%	
	V	88.8 kN	81.75 kN	-7.9%	
Beam B5	BM	355.2 kNm	346.7 kNm	-2.4%	
	V	88.8 kN	93.5 kN	+5.3%	
Column C1	Fx	355.2 kN	363 kN	+2.2%	
All beams are within acceptable loading allowance.					

Calculation Sheet

BDP.

JOB TITLE	Irwell House.		
JOB NUMBER			
ELEMENT	Second Floor Loading	CALC SHEET NUMBER	SFL08
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p>Propose Beam to Column Stiffening</p>  <p>10mm thick plate welded onto existing angle cleat connection</p> <p>Stiffen connection is needed to reassure propose beam loadings can be transfered on to the columns.</p>	

5.0 Wind Load

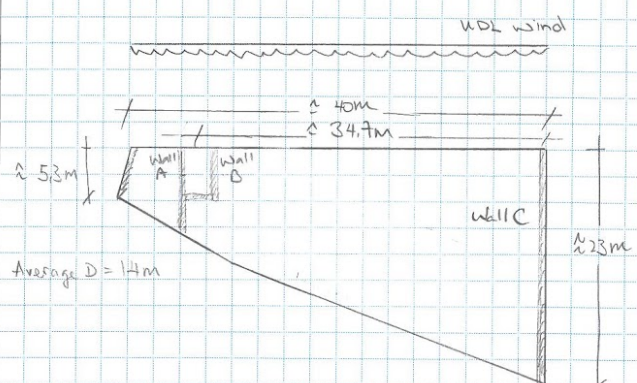
With the proposed 52ft long polytunnel at roof level, this would increase the pickup of wind load and increase loadings apply to top of shear walls.

In this section calculation is done to check if the overturning effect of the shear walls is acceptable with the increased wind load.

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER		
Irwell House.			
ELEMENT	CALC SHEET NUMBER		
Wind load - Existing Condition	PTW 01		
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	 <p>height of building = 10.5m</p> <p>wind load calculation to BS 6399-2</p>	
Table 1	$k_b = 1$	
Fig 3	$H = 10.5$ $\therefore C_r = 0.02$	
2.2.2.1	site wind speed $v_s = v_b \times S_a \times S_d \times S_s \times S_p$	
Fig 6	@ Manchester basic wind speed $v_b = 23 \text{ m/s}$	$v_b = 23 \text{ m/s}$
2.2.2.2	altitude factor $S_a = 1 + 0.001 A_s$	
	$A_s = \text{site altitude} = 28 \text{ m (Goope Earth)}$	
	$S_a = 1 + 0.001 \times 28 = 1.028$	$S_a = 1.028$
2.2.2.3	direction factor $S_d = 1$ (ignore building orientation)	$S_d = 1$

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Existing Condition	PTW 02
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT																				
2.2.2.4	seasonal factor $S_s = 1$ permanent	$S_s = 1$																				
2.2.2.5	probability factor $S_p = 1$	$S_p = 1$																				
	$\therefore V_S = 23 \times 1.028 \times 1 \times 1 \times 1$ $= 23.6 \text{ m/s}$	$V_S = 23.6 \text{ m/s}$																				
2.2.3.1	effective wind speed $V_e = V_S \times S_b$																					
2.2.3.3	terrain and building factor S_b																					
Table 4	$H_e = 10.5 \text{ m}$ in town closest distance to sea = 50 km																					
	<table><tr><td></td><td colspan="3">km</td></tr><tr><td>H_e</td><td>10</td><td>50</td><td>100</td></tr><tr><td>10</td><td>1.68</td><td>1.63</td><td>1.58</td></tr><tr><td>10.5</td><td></td><td><u>1.64</u></td><td></td></tr><tr><td>15</td><td>1.82</td><td>1.765</td><td>1.71</td></tr></table>		km			H_e	10	50	100	10	1.68	1.63	1.58	10.5		<u>1.64</u>		15	1.82	1.765	1.71	
	km																					
H_e	10	50	100																			
10	1.68	1.63	1.58																			
10.5		<u>1.64</u>																				
15	1.82	1.765	1.71																			
	$\therefore V_e = 23.6 \times 1.64 = 38.7 \text{ m/s}$	$V_e = 38.7 \text{ m/s}$																				
2.1.2.1	Dynamic Pressure $q_s = 0.613 V_e^2$																					
	$q_s = 0.613 \times 38.7^2 = 903.9 \text{ Pa}^3$																					
	$1 \text{ Pa} = 1 \text{ N/m}^2 \quad \therefore = 0.9 \text{ kN/m}^2$	$q_s = 0.9 \text{ kN/m}^2$																				

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Existing Condition	PTW 03
DRAWING REF	

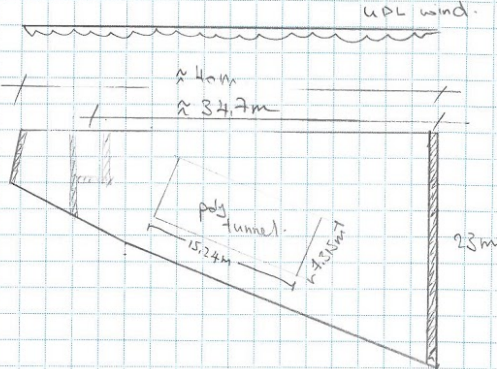
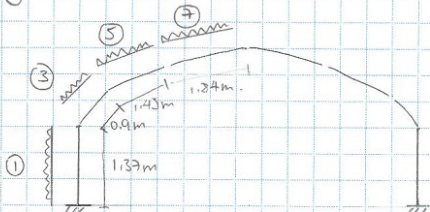
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
2-1.3.1	External surface pressure.	
	$p_e = q_s C_{pe} C_a$	
Fig 4	Diagonal dimension $a =$	
	$a = \sqrt{(40^2 + 10.5^2)} = 41.3$	
	line B $\therefore C_a = 0.84$	
Table S & Fig 12	External pressure coefficient C_{pe}	
	$D/H = 14 / 10.5 = 1.3$	
	$\therefore C_{pe} = 0.775$	
	\therefore wind load on building elevation	
	$= 0.9 \text{ kN/m}^2 \times 0.84 \times 0.775$	
	$= \underline{\underline{0.6 \text{ kN/m}^2}}$	$p_e =$
		$\underline{\underline{0.6 \text{ kN/m}^2}}$

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER		
Irwell House.			
ELEMENT	CALC SHEET NUMBER		
Wind load - Proposed Condition.	PTW 04		
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<div></div> <p>Calculate total wind load apply to poly tunnel. north elevation.</p> <p>From previous poly tunnel wind calculation.</p> <p>Poly tunnel cross section.</p> <div></div> <div><p>① = $0.34 \text{ kN/m}^2 \times 1.37 \text{ m} \times 15.24 \text{ m} = 7.1 \text{ kN}$</p><p>③ = $0.376 \text{ kN/m}^2 \times 0.9 \text{ m} \times 15.24 \text{ m} = 5.2 \text{ kN}$</p><p>⑤ = $0.141 \text{ kN/m}^2 \times 1.45 \text{ m} \times 15.24 \text{ m} = 3.1 \text{ kN}$</p><p>⑦ = $0.047 \text{ kN/m}^2 \times 1.84 \text{ m} \times 15.24 \text{ m} = 1.3 \text{ kN}$</p></div>	<div><p>Total</p><p>= $7.1 + 5.2 + 3.1 + 1.3$</p><p>= <u>16.7 kN</u></p></div>

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 05
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

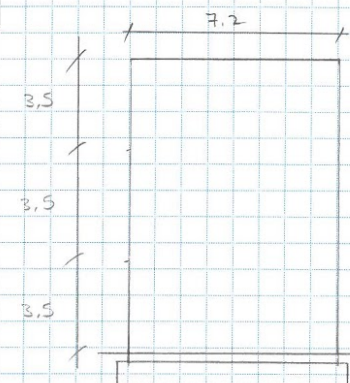
REFERENCE	CALCULATIONS	OUTPUT
	<p>Consider walls A + B as most heavily loaded walls.</p> <p>Wall stiffness.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Wall A</p> <p>0.215</p> <p>7.2</p> <p>IA</p> </div> <div style="text-align: center;"> <p>Wall B</p> <p>0.215</p> <p>5</p> <p>IB</p> </div> </div> <p>Brick = 20 kN/m³</p> $I_A = 0.215 \times 7.2^3 / 12 = 6.7 \text{ m}^4$ $I_B = 0.215 \times 5^3 / 12 = 2.2 \text{ m}^4$ <p>∴ wall A takes 75% of load.</p> <p>wall B takes 25% of load</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 06
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

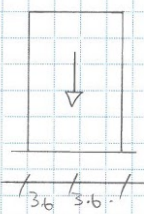
REFERENCE	CALCULATIONS	OUTPUT
	<p>Wind load to wall A. wind load width = 18m</p>  <p>Existing Proposed</p> <p>W = $0.6 \times 1.75 \times 18 \times 0.75$ W = $(0.6 \times 1.75 \times 18 + 9) \times 0.75$ = 14 kN = 21 kN</p> <p>W = $0.6 \times 3.5 \times 18 \times 0.75$ W = 28.4 kN = 28.4 kN</p> <p>W = 28.4 kN W = 28.4 kN</p> <p>Existing load Moment</p> <p>M = $28.4 \times 3.5 + 28.4 \times 7 + 14 \times 10.5$ = 445.2 kNm</p> <p>Proposed load Moment</p> <p>M = $28.4 \times 3.5 + 28.4 \times 7 + 21 \times 10.5$ = 518.7 kNm</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW07
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Wall A resisting moment.</u></p> <p><u>Wall A Dead load.</u></p> <p>Self weight = $20 \times 0.215 \times 10.5 \times 7.2$ $= 325 \text{ kN.}$</p> <p>Slab load = load area = $2m \times 7.2m = 14.4m^2$ $= 5 \text{ kN/m}^2 \times 14.4m^2$ $= 72 \text{ kN. per floor.}$</p> <p>total slab = 72×3 $= 216 \text{ kN.}$</p> <p>Total = $325 + 216 = 541 \text{ kN.}$</p> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> $M = 541 \times 7.2 / 4$ $= 973.8 \text{ kNm.}$ </div> </div> <p>Existing safety factor = $973.8 / 445.2$ load = 2.2</p> <p>Propose safety factor = $973.8 / 518.7$ load = 1.9</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 08
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE
HL	March 13

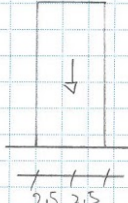
REFERENCE	CALCULATIONS	OUTPUT
	<p>Wind load to wall B wind load width = 18m</p> <p>Existing Proposed</p> <p> $w = 0.6 \times 1.75 \times 18 \times 0.25 = 4.7 \text{ kN}$ $w = (0.6 \times 1.75 \times 18 + 9) \times 0.25 = 7 \text{ kN}$ </p> <p> $w = 0.6 \times 3.5 \times 18 \times 0.25 = 9.5 \text{ kN}$ $w = 9.5 \text{ kN}$ </p> <p> $w = 9.5 \text{ kN}$ $w = 9.5 \text{ kN}$ </p> <p>Existing load moment</p> <p> $M = 1.5 \times 3.5 + 9.5 \times 7 + 4.7 \times 10.5$ $= 149.1 \text{ kNm}$ </p> <p>Propose load moment</p> <p> $M = 9.5 \times 3.5 + 9.5 \times 7 + 7 \times 10.5$ $= 173.3 \text{ kNm}$ </p>	

Calculation Sheet

BDP.

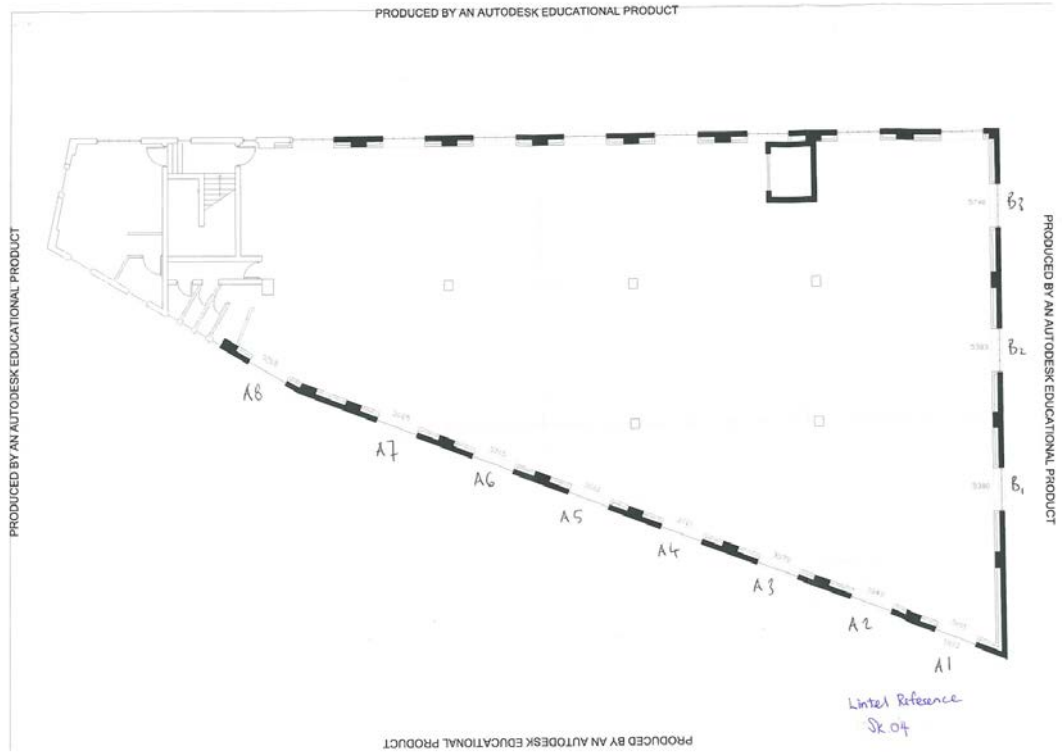
JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 09
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Wall B resisting moment</u></p> <p><u>Wall B Dead load</u></p> <p>selfweight = $20 \times 0.215 \times 10.5 \times 5$ $= 225.75 \text{ kN}$</p> <p>slab = $5 \text{ kN/m}^2 \times 0.6 \times 5 \times 3 = 45 \text{ kN}$ stair = $3 \text{ kN/m}^2 \times 1 \times 2.5 \times 2 = 15 \text{ kN}$</p>  <p>$M = 285.8 \times 5 / 4$ $= 357 \text{ kNm}$</p> <p>Existing safety factor = $357 / 149.1$ load = 2.4</p> <p>Propose safety factor = $357 / 173.3$ load = 2.1</p>	

6.0 Lintel Design

As the existing lintels are damaged, new lintels are needed for replacement.

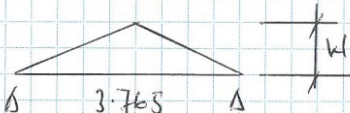


Calculation Sheet

BDP.

JOB TITLE	IRWELL HOUSE	JOB NUMBER	
ELEMENT	LINTEL TYPE A	CALC SHEET NUMBER	A1
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
			3/2013

REFERENCE	CALCULATIONS	OUTPUT
	<p>Max span = 3.765 m (A1 to A8) (inside face of piers)</p> <p>$G_u = 5 \text{ kN/m}^2$</p> <p>$Q_u = 0.6 + 0.2 = 0.8 \text{ kN/m}^2$</p>  <p>$W = (1.4 \cdot 5.0 \cdot 0.93) + (1.6 \cdot 0.8 \cdot 0.93)$ $= 7.70 \text{ kN/m}$</p> <p>Also consider wt. of brickwork over</p> <p>$\therefore \text{Allow } W = 18 \cdot 0.215 \cdot 0.75 = 3.0 \text{ kN/m}$ $\times 1.4$ $= 4.2 \text{ kN/m}$</p> <p>$M = \frac{7.70 \cdot 3.765^2}{12} + \frac{4.2 \cdot 3.765^2}{8}$ $= 9.1 + 7.4 = 16.5 \text{ kNm}$</p>	

Calculation Sheet

BDP.

JOB TITLE	16mm WARE	JOB NUMBER	
ELEMENT	Lintel type A	CALC SHEET NUMBER	A2
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JK	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	$P_v = \frac{7.70 \cdot 1.765}{4} + \frac{4.2 \cdot 3.765}{2}$ $= 15.2 \text{ kN. (factored)}$	
	$\text{Unfactored Reaction} = \frac{15.2}{1.4} = 10.9 \text{ kN.}$ <p>(for Anchor fixing)</p>	
	<p>try 150 x 90 PFC</p> <p>for $L_E = 3.7\text{m}$ $M_b = 32 \text{ kNm.}$</p>	
	$\delta_{max} = \left[\frac{WL^4}{120 EI} + \frac{5WL^4}{384 EI} \right] / 1.4$ $= \left[\frac{7.70 \cdot 3.765^4 \times 10^3}{120 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} + \frac{5 \cdot 4.2 \cdot 3.765^4 \times 10^3}{384 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} \right] / 1.4$	


Calculation Sheet

BDP.

JOB TITLE	IRWILL WASTE			JOB NUMBER	
ELEMENT	LINTER TYPE A			CALC SHEET NUMBER	A3/REV A
DRAWING REF					
CHECKED BY	DATE	CALCULATIONS BY	DATE		
		JR	3/2013		

REFERENCE	CALCULATIONS	OUTPUT
	$= \left[5.4 + 4.6 \right] / 1.4 = 7.1 \text{ mm}$ $= \text{span} / 530$ <p>\therefore USE <u>150 x 90 PFC</u></p> <p>Support fixings:</p> <p>(Assuming 3 bolts in a row vertically at 160 c/c)</p> $F_v = 3 \times 6.1 = 18.3 \text{ kN} > 10.9 \text{ kN}$ <p>\therefore USE <u>3 NO. M12 RAWLOK BOLTS</u></p>	OK✓

BDP.

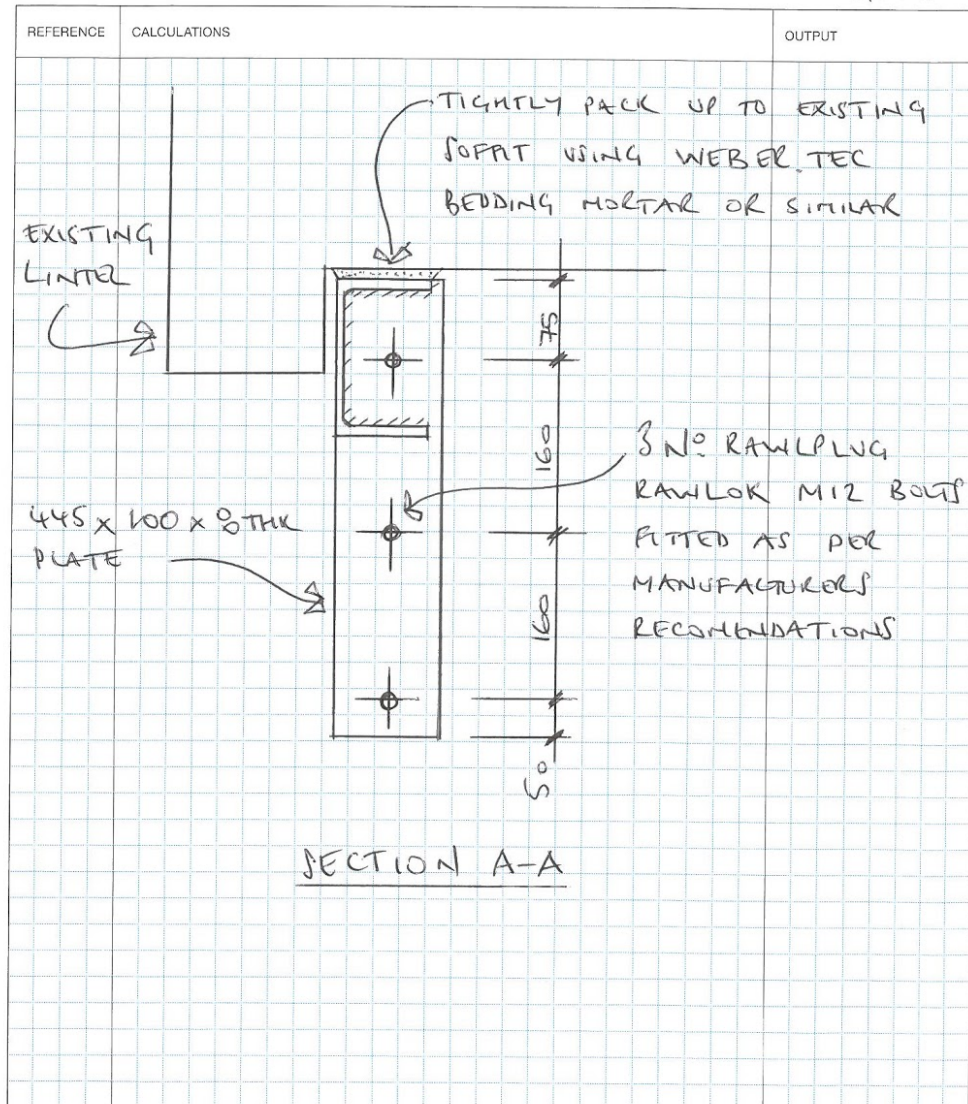
CHECKED BY	DATE	CALCULATIONS BY	DATE
			27/02/2013

REFERENCE	CALCULATIONS	OUTPUT
	<p>Pack to underside of slabs Using Epoxy based mortar</p> <p>150 x 90 PFC</p> <p>FACE OF PIER</p> <p>FACE OF PIER</p> <p>FACE OF PIER</p> <p>FACE OF PIER</p> <p>EXTN OPENING</p> <p>ELEVATION - U-TYPE A</p>	

Calculation Sheet

BDP.

JOB TITLE	12 WELL WASTE			JOB NUMBER	
ELEMENT	LIMTEL TYPE A			CALC SHEET NUMBER	
DRAWING REF					AS/RVA
CHECKED BY	DATE	CALCULATIONS BY	DATE		
		JR	3/2013		

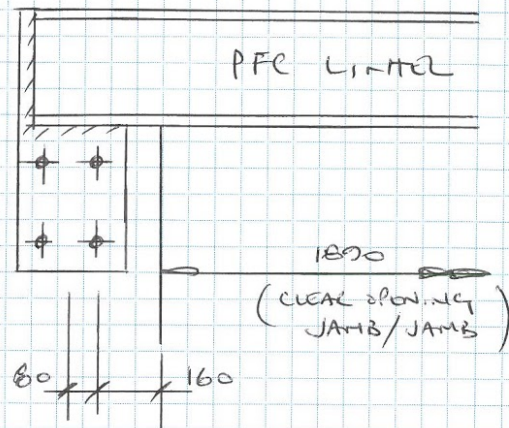
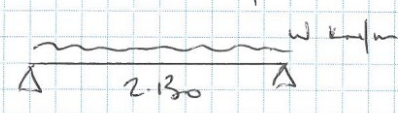


Calculation Sheet

BDP.

JOB TITLE	IRWILL HOUSE	JOB NUMBER	
ELEMENT	LINTER TYPE B	CALC SHEET NUMBER	51
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JF	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>LINTER TYPE B</u></p>  <p>Assuming 4 bolt connection detail</p> <p>PFC span = $1.80 + 0.16 + 0.08$ $= 2.130 \text{ m}$</p> <p>$G_u = 5 \text{ kN/m}^2$</p> <p>$Q_u = \text{say } 1.5 \text{ kN/m}^2$</p> 	

Calculation Sheet

BDP.

JOB TITLE	12W22 HOSE		
JOB NUMBER			
ELEMENT	UNITED TYPE B	CALC SHEET NUMBER	82
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		AK	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	$W = (1.4 \cdot 5.0 \cdot 2.0)$ $+ (1.6 \cdot 1.5 \cdot 2.0)$ $+ (1.4 \cdot 18 \cdot 0.25 \cdot 0.75)$ $= 22.9 \text{ kN/m}$	(14) (4.6) (4.1)
	$M = \frac{22.9 \cdot 2.13^2}{8} = 12.98 \text{ kNm}$	
	by inspection 150 x 90 PFC OK for bending moment.	
	Check deflection:	
	$\delta = \left[\frac{5 \cdot 22.9 \times 2.13^4 \times 10^3}{384 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} \right] / 1.4$ $= 1.84 \text{ mm} \quad \checkmark \text{ OK}$	
	\therefore USE 150 x 90 PFC.	

Calculation Sheet

BDP.

JOB TITLE	12mm waste		
JOB NUMBER			
ELEMENT	Lintel type B		B3
CALC SHEET NUMBER			
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		<i>[Signature]</i>	3/2018

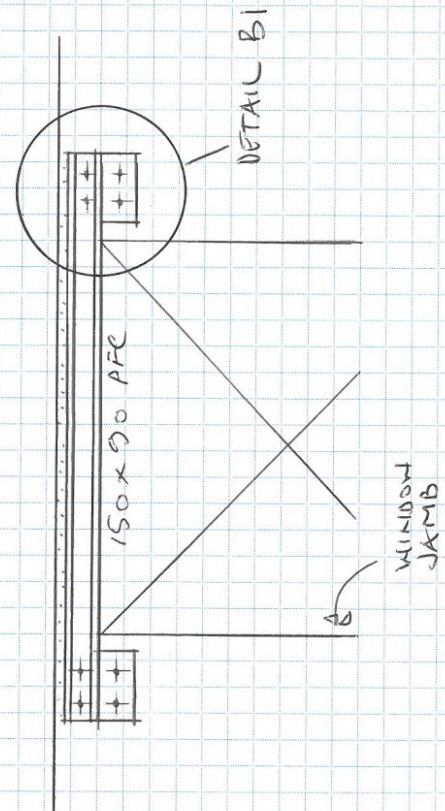
REFERENCE	CALCULATIONS	OUTPUT
	<p>Support Fixings:</p> $F_v = \left(\frac{22.9}{1.4} \right) \cdot \frac{2 \cdot 130}{2} = 17.4 \text{ kN}$ <p>Capacity of 4 N° M12 RAWLOK bolts</p> $= 4 \times 6.1 = 24.4 \text{ kN OK} \checkmark$ <p>\therefore Use <u>4 N° M12 RAWLOK BOLTS.</u></p>	

Calculation Sheet

BDP.

JOB TITLE	ikwal naye	JOB NUMBER	
ELEMENT	Lintel Type B	CALC SHEET NUMBER	84
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JR	3/2013

REFERENCE	CALCULATIONS	OUTPUT
		<p>ELEVATION - Lintel Type B</p>

Calculation Sheet

BDP.

JOB TITLE	1RWEI WASE	JOB NUMBER	
ELEMENT	LINTEL TYPE B	CALC SHEET NUMBER	
DRAWING REF			
CHECKED BY		DATE	
		CALCULATIONS BY	
			DATE

85

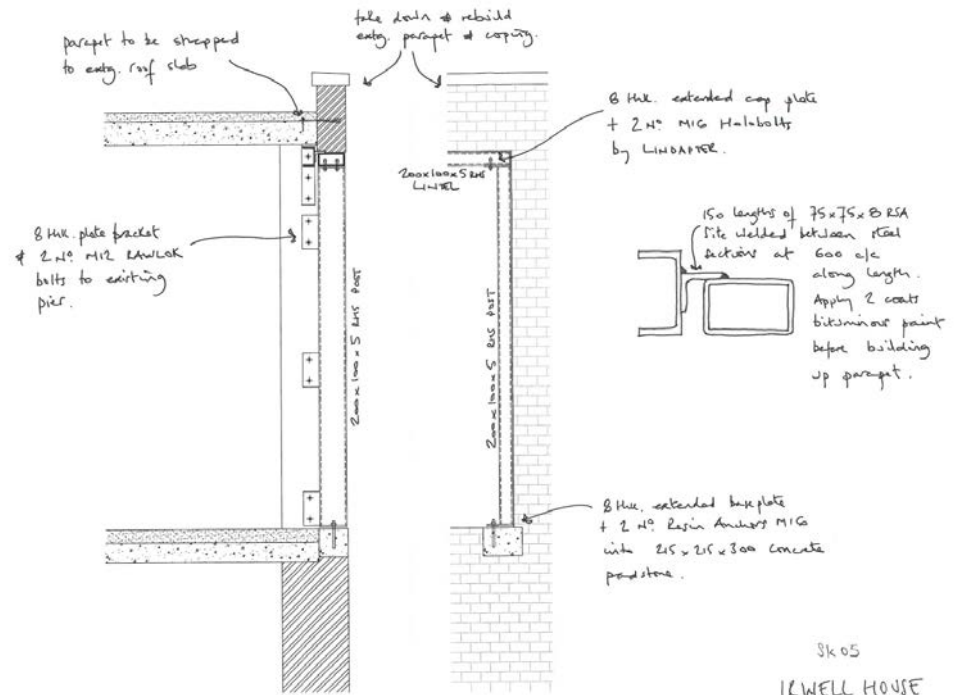
REFERENCE	CALCULATIONS	OUTPUT
	<p>4 NO M12 RAWLOK BOLTS BY RAWLPWLY</p> <p>150x30 PFC</p> <p>WINDOW JAMB</p> <p>75</p> <p>160</p> <p>50</p> <p>110</p> <p>50</p> <p>160</p> <p>50</p> <p>135x260x8 PLATE</p> <p>DETAIL B1</p>	

Calculation Sheet

BDP.

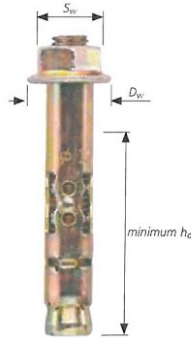
JOB TITLE	JOB NUMBER
IRWELL HOJIE	
ELEMENT	CALC SHEET NUMBER
LINTEL TO BIO WALL	BW/1
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE

REFERENCE	CALCULATIONS	OUTPUT
	<p>Span = 3.22 m</p> <p>$w = 1.4 \cdot 0.7 \cdot 0.3 \cdot 18 = 5.3 \text{ kN/m}$ (conservative load)</p> <p>$M = \frac{wL^2}{8} = \frac{5.3 \cdot 3.22^2}{8} = 6.89 \text{ kNm}$</p> <p>Try 200 x 100 x 5 RNS on <u>MINOR</u> axis.</p> <p>for 200 x 100 x 5 RNS $M_{cy} = 18.9 \text{ kNm OK} \checkmark$</p> <p>Check deflection..</p> <p>$\delta = \frac{5}{384} \frac{wL^4}{EI}$</p> <p>$= \frac{5}{384} \frac{(5.3/1.4) \cdot 3.22^4 \times 10^3}{205 \times 10^6 \cdot 505 \times 10^{-8}}$</p> <p>$= 5.1 \text{ mm}$</p> <p>Allowable $\delta = \text{span} / 250 = 13 \text{ mm OK} \checkmark$</p> <p>USE: <u>200 x 100 x 5 RNS (MINOR)</u></p>	



BIO FACADE - STRUCTURAL OPENING
BDP - JPP - 6/3/2013

Product Information



DESCRIPTION

The Rawlok® is a torque controlled expansion anchor comprising a split sleeve and a bolt incorporating an expander wedge.

It is a through fixing, thus allowing the hole in the substrate to be drilled through the pre-positioned fixture, eliminating the need for marking out, ensuring fast and simple installation.

SUITABLE FOR USE IN:

Concrete
Brickwork
Blockwork
Stone.

FEATURES

1. Bolt and drill size marked on sleeve to ensure correct installation.
2. Integral collapse feature to ensure maximum clamping force is applied to the fixture.
3. Anchor designed for optimum performance in most base material types.
3. One piece flange nut.

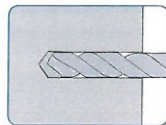
TYPICAL APPLICATIONS

- Stadium seating
- Radiators
- Satellite dishes
- Signs
- Shutters
- Garage doors

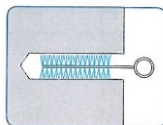
RAWLOK® Bolt Projecting - Zinc plated

BOLT SIZE (G)	BOLT LENGTH (mm) (L)	NUT DIAMETER (mm) (A)	FLANGE DIAMETER (mm) (D _{fl})	MAXIMUM FIXTURE THICKNESS (mm) (T _{fix})	MINIMUM HOLE DEPTH IN STRUCTURE (mm) (h _o)	MINIMUM EFFECTIVE EMBEDMENT DEPTH (mm) (h _{ed})	MINIMUM SUBSTRATE THICKNESS (mm) (t _{min})	HOLE DIAMETER		RECOMMENDED TIGHTENING TORQUE (Nm)				(ZINC PLATED)	
								IN FIXTURE (mm) (d _f)	IN STRUCTURE (mm) (d _s)	CONCRETE 30N/mm ² (T _{res})	BRICKWORK 20.5N/mm ² (T _{res})	BLOCKWORK 14N/mm ² (T _{res})	BLOCKWORK 7N/mm ² (T _{res})	PRODUCT CODE	NEW CODE
M5	56	8	12	25	30	26	50	8	6.5	2.5	2.5	1.5	1.0	69-506	RLK-P-05056
M6	40	10	14	10	35	26	55	10	8	6.0	6.0	3.0	2.0	69-508	RLK-P-06040
	65			35										69-510	RLK-P-06065
M8	50	13	17	10	40	36	65	12	10	11.0	11.0	6.0	4.0	69-514	RLK-P-08050
	75			36										69-516	RLK-P-08075
	95			55										69-518	RLK-P-08095
	60			10										69-520	RLK-P-10060
M10	75	15	21	27	55	43	85	14	12	22.0	22.0	11.0	8.0	69-522	RLK-P-10070
	100			50										69-524	RLK-P-10100
	130			80										69-525	RLK-P-10130
	110			55										69-528	RLK-P-12110
M12	145	18	26	85	60	50	90	18	16	38.0	38.0	25.0	12.0	69-530	RLK-P-12145

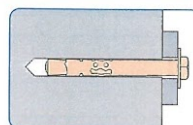
Installation



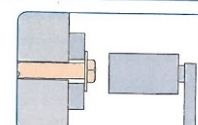
1. Drill a hole of required diameter and depth.
Note: Fixing into mortar joints should be avoided.



2. Remove debris and thoroughly clean hole with brush and pump.



3. Insert Rawlok® Sleeve Anchor through the fixture into the hole.



4. Tighten to recommended torque with torque wrench.

Ex 02

Specification Data

RAWLOK® Bolt Projecting Performance Data

SIZE	CONCRETE, $f_{ck, cube} = 30 \text{ N/mm}^2$ (C20/25)								
	CHARACTERISTIC LOAD (kN)		DESIGN LOAD FACTORED (kN)		RECOMMENDED LOAD UNFACTORED (kN)		CHARACTERISTIC EDGE DISTANCE (mm)		CHARACTERISTIC SPACING (mm)
	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION ($C_{ed,N}$)	SHEAR ($C_{ed,V}$)	TENSION & SHEAR ($S_{ed,N}$ ($S_{ed,V}$))
M5	5.0	3.6	2.3	2.0	1.9	1.9	60	60	60
M6	6.9	5.4	3.2	3.0	2.7	2.5	70	80	80
M8	9.3	9.0	4.3	5.0	3.6	4.2	80	100	100
M10	11.4	12.6	5.3	7.0	4.4	5.8	100	120	120
M12	14.5	19.8	6.7	11.0	5.6	9.2	120	160	160

SIZE	BRICKWORK, $f_{ck} = 20 \text{ N/mm}^2$						BLOCKWORK, $f_{ck} = 14 \text{ N/mm}^2$						BLOCKWORK, $f_{ck} = 7 \text{ N/mm}^2$					
	CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)		CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)		CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)	
	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})
M5	2.4	3.4	1.1	1.9	0.9	1.6	1.9	3.4	0.9	1.9	0.8	1.6	1.5	2.3	0.7	1.3	0.6	1.1
M6	3.7	5.2	1.7	2.9	1.4	2.4	3.2	5.2	1.5	2.9	1.3	2.4	2.4	2.5	1.1	1.4	0.9	1.2
M8	5.0	8.6	2.3	4.8	1.9	4.0	4.5	8.6	2.1	4.8	1.8	4.0	3.5	2.7	1.6	1.5	1.3	1.3
M10	6.0	10.3	2.8	5.7	2.3	4.8	5.6	10.3	2.6	5.7	2.2	4.8	4.5	3.1	2.1	1.7	1.8	1.4
M12	7.3	13.1	3.4	7.3	2.8	6.1	6.9	13.1	3.2	7.3	2.7	6.1	5.8	3.4	2.7	1.9	2.3	1.6

For further explanations on calculations please see pages 10 and 11
When calculating loads in brickwork and blockwork apply the published edge distance and spacing for concrete and assume these figures to be the absolute minimums. Concrete reduction factors must NOT be applied.

Reduction Factors - Edge and Spacing Distances for Rawlok® Sleeve Anchor Bolt Projecting.

The full characteristic edge and spacing distances shown in the table above are the minimum allowable for the quoted DESIGN RESISTANCE or RECOMMENDED LOAD, depending on your design method.

Where these dimensions are not achievable, the appropriate reduction factor/s from the tables below must be applied to the DESIGN RESISTANCE or RECOMMENDED LOAD.
Choose the required bolt diameter across the top of the appropriate table and read down the left hand column until actual edge or spacing distance is found.

Read off the reduction factor where the two lines intersect (interpolate as required).
Multiply this factor by the DESIGN RESISTANCE or RECOMMENDED LOAD quoted in the table.
On the occasion that multiple close edge and/or spacing distances occur, the appropriate reduction factors must be applied.

Edge Distance (Concrete Only)

EDGE (mm)	TENSILE: EDGE REDUCTION FACTORS					EDGE (mm)	SHEAR: EDGE REDUCTION FACTORS				
	M5	M6	M8	M10	M12		M5	M6	M8	M10	M12
40	0.75					40	0.58				
50	0.87	0.79				50	0.79	0.53			
60	1.00	0.89	0.81			60	1.00	0.69	0.50		
70		1.00	0.91	0.77		70		0.84	0.62	0.48	
80			1.00	0.85		80		1.00	0.75	0.58	
90				0.92	0.81	90			0.87	0.69	0.45
100				1.00	0.87	100			1.00	0.79	0.53
120						120				1.00	0.69
140						140					0.84
160						160					1.00

Spacing (Concrete Only)

SPACING (mm)	TENSILE & SHEAR REDUCTION FACTORS				
	M5	M6	M8	M10	M12
40	0.80				
50	0.90	0.77			
60	1.00	0.85	0.76		
70		0.92	0.82	0.75	
80		1.00	0.88	0.80	
90			0.94	0.85	0.74
100			1.00	0.90	0.77
120				1.00	0.85
140					0.92
160					1.00

7.0 Sketches / Extract References

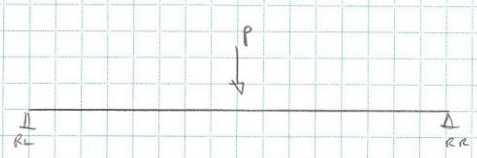
Roof Level Beam Reference	SK01
Beam reactions with proposed loadings	SK02
Second Floor Propose Layout Beam Reference	SK03
Lintel Reference	SK04
B10 Façade – Structural Opening	SK05
Historial Structural Steelwork Handbook –	
Imposed loads from BS449 1948	EX01
Rawlok Bolt Production Information	EX02

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Inwell House	
ELEMENT	CALC SHEET NUMBER
Poly tunnel @ Roof	PTR 23
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

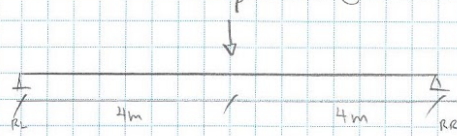

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams.</u></p> <p>Primary beam <u>Beam B8.</u></p> <p>Beam length = 8m.</p> <p>point load @ 4m , B2 & B5 reactions.</p>  $P = B2 R_L + B5 R_L$ $= 71.5 + 68.1 = 139.6 \text{ kN}$ <p><u>Bending Moment</u></p> $= \frac{PL}{4} = 139.6 \times 8 / 4 = 279.2 \text{ kNm}$ <p><u>Reactions.</u></p> $= P/2 = 139.6 / 2 = 69.8 \text{ kN}$ <p>Compare with existing. $BM = 273.2 \text{ kNm}$ $V = 68.3 \text{ kN}$</p> <p>BM increase +2.2 %</p> <p>V increase +2.2 %</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR24
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

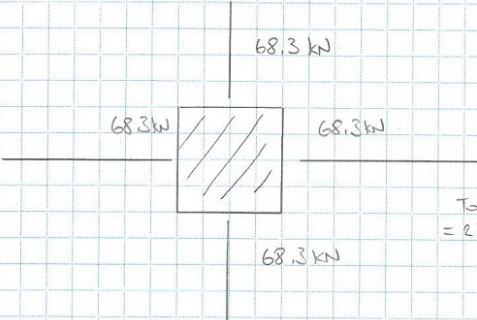
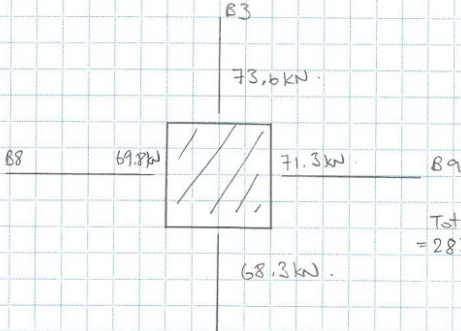
REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Proposed load on beams</u></p> <p>Primary beam <u>Beam B9</u></p> <p>Beam length = 8m.</p> <p>point load @ 4m.</p> <p>Existing Secondary beam reaction of Polytunnel.</p>  <p>Secondary beam reaction = Dead + Imposed $= 61 + 7.3 = 68.3 \text{ kN} \times 2 = 136.6 \text{ kN}.$</p> <p>Beam B9a snowdrift reaction \rightarrow</p>  <p>$\text{VOL} = 0.6 \times 4 = 2.4 \text{ kN/m}.$ $R_R = (2.4 \times 6) / 2 \times 2/3 = 4.8 \text{ kN}.$</p> <p>Polytunnel. load width = 4.3m.</p> <p>\therefore point load = 1.6 kN</p> <p>wind pointload = $x = -4.6 \text{ kN}$ $y = +0.7 \text{ kN}.$ $M_x = -4.6 \text{ kNm}.$</p>	<p><u>Summary</u></p> <p>All beams are within 10% allowable increase</p>
STAAD analysis	<p><u>Bending moment</u> = 290 kNm.</p> <p><u>Reaction left</u> = $x = -2.3 \text{ kN}$ (horizontal) $y = 71.3$ (vertical)</p> <p><u>Reaction right</u> = $x = -2.3 \text{ kN}$ (horizontal) $y = 72.4$ (vertical)</p>	<p>Compare with Existing.</p> <p>BM = 273.2 kNm</p> <p>V = 68.3 kN.</p> <p>+ 6.1%</p> <p>+ 4.4%</p> <p>+ 6%</p>

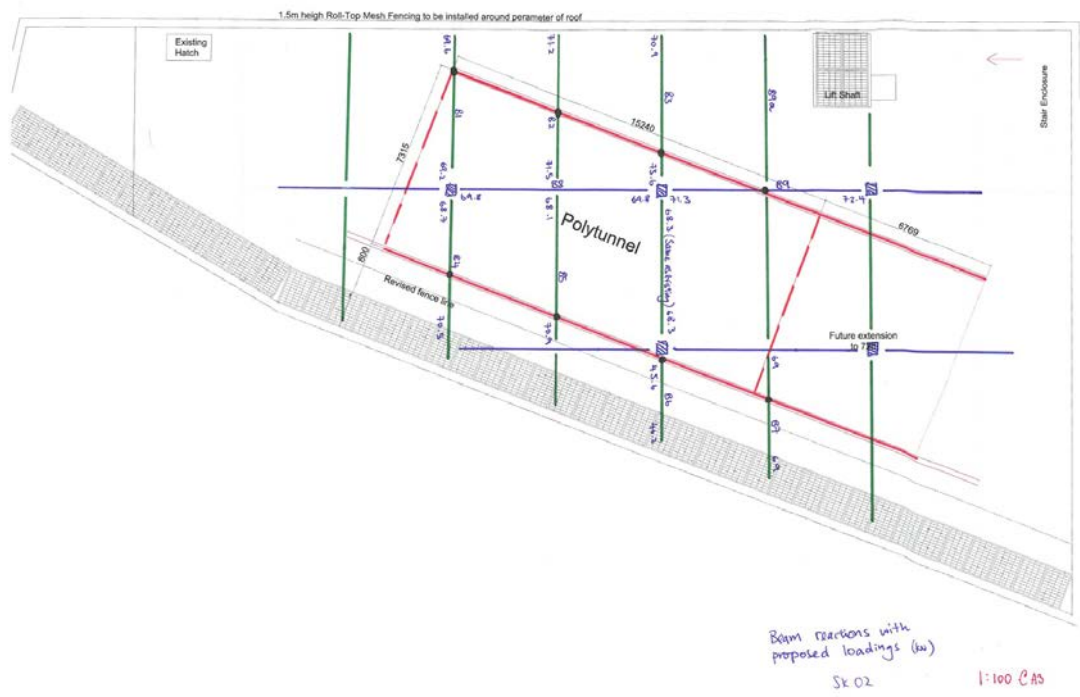
Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel @ Roof	PTR25
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p>Existing load on column. C1</p>  <p>Total = 273.2 kN.</p>	
	 <p>Total = 283 kN.</p>	



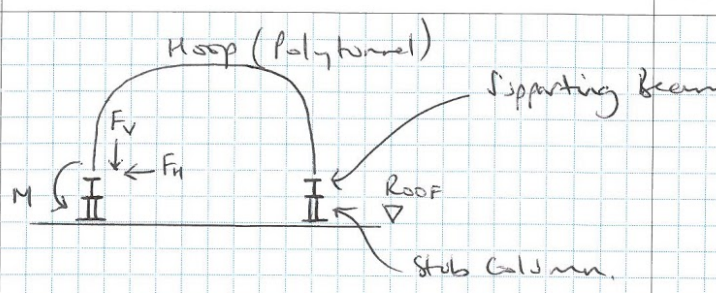
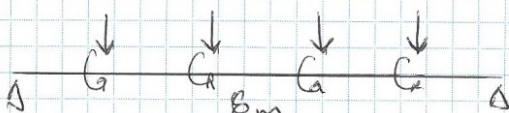
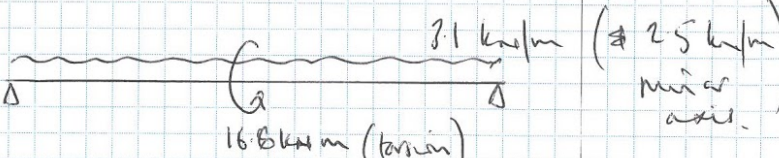
3.0 Polytunnel Supporting Beam

To only allow the polytunnel to be supported by the secondary beams, supporting beams are designed to transfer the polytunnel loading as point loads onto the secondary beams.

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER		
Ipsell House			
ELEMENT	CALC SHEET NUMBER		
Polytunnel Supporting beam	PTB 01		
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		JP	March 13

REFERENCE	CALCULATIONS	OUTPUT
	 <p>Worse case loading from dead and imposed load (snow load)</p> $F_v = 6.1 \text{ kN per hoop} \times 4/8 = 3.1 \text{ kN/m}$ $F_h = 4.9 \text{ kN per hoop} \times 4/8 = 2.5 \text{ kN/m}$ $M = 4.2 \text{ kNm} \times 4 = 16.8 \text{ kNm (torque)}$  <p>Equivalent UDL</p> 	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Polytunnel Supporting Beam	PTB 02
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JP	March 13


REFERENCE	CALCULATIONS	OUTPUT
	$M_x = 3.1 \cdot 8^2 / 8 = 24.8 \text{ kNm}$ $M_y = 2.8 \cdot 8^2 / 8 = 22.4 \text{ kNm}$ $\text{Max Shear} = 3.1 \times 2 = 6.2 \text{ kN}$	

Calculation Sheet

BDP.

JOB TITLE	Irwell House			JOB NUMBER	
ELEMENT	Polytunnel Supporting Beam			CALC SHEET NUMBER	PTB 03
DRAWING REF					
CHECKED BY	DATE	CALCULATIONS BY	DATE		
		JP	March 13		

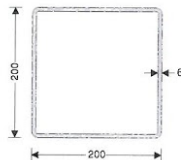
REFERENCE	CALCULATIONS	OUTPUT
	<p>Check Deflection.</p> <p>Assumed size 200 x 200 x 5 S.W.</p> $\delta = \frac{5}{384} \cdot \frac{(3.1 / 1.4) 8.0^4}{205 \times 10^6 \cdot 2410 \times 10^{-8}} \times 10^3$ <p>= 24 mm. OK ✓</p>	

 Tedds BDP 11 Ducie Street Manchester	Project <i>Irwell House</i>		Job no.	
	Calcs for <i>Polytunnel Supporting Beam</i>		Start page no./Revision <i>PTB04</i>	
	Calcs by <i>J</i>	Calcs date <i>08/03/2013</i>	Checked by	Checked date
				Approved date

STEEL BEAM TORSION DESIGN

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

Tedds calculation version 2.0.01



Section details

Section type SHS 200x200x6.0
 Steel grade S355
 Design strength $p_{yw} = p_y = 355 \text{ N/mm}^2$
 Constant $\epsilon = \sqrt{(275 \text{ N/mm}^2 / p_y)} = 0.880$

Calculated torsional properties

Height of web $d_x = b_y = D - 3 \times t = 182.0 \text{ mm}$
 Width of flange $b_x = d_y = B - 3 \times t = 182.0 \text{ mm}$
 Shear area - y $A_{vy} = A \times D / (D + B) = 23.1 \text{ cm}^2$
 Shear area - x $A_{vx} = A \times B / (D + B) = 23.1 \text{ cm}^2$
 $d_{vx} = A_{vx} / (2 \times t) = 192.4 \text{ mm}$
 $d_{vy} = A_{vy} / (2 \times t) = 192.4 \text{ mm}$
 Plastic modulus of web $S_{wx} = 2 \times t \times d_{vy}^2 / 4 = 111.0 \text{ cm}^3$
 Plastic modulus of flange $S_{wy} = 2 \times t \times d_{vx}^2 / 4 = 111.0 \text{ cm}^3$
 Statical moment at mid-depth of section $Q_{tw} = S_x / 2 = 167 \text{ cm}^3$

Geometry - Beam unrestrained against lateral-torsional buckling between supports.

Effective span $L = 8000 \text{ mm}$
 Length of segment for LT buckling $L_{LT} = 8000 \text{ mm}$
 Compression flanges laterally unrestrained
 Partial torsional restraint against rotation about longitudinal axis provided by connection of bottom flange to supports
 Effective length for LT buckling $L_{E,LT} = L_{LT} \times 1.2 + 2 \times D = 10000 \text{ mm}$

Loading - Torsional loading comprises only full-length uniformly distributed load(s)

Internal forces & moments on member under factored loading for ult design


Applied shear force $F_{vy} = 6.2 \text{ kN}$
 Maximum bending moment $M_{LT} = M_k = 24.80 \text{ kNm}$
 Applied torque $T_q = 16.80 \text{ kNm}$
 Minor axis bending moment $M_y = 0 \text{ kNm}$
 Compression force $F_c = 0 \text{ kN}$

Equivalent uniform moment factors

EUM factor (Cl. 4.3.6.6 and T18) $m_{LT} = 1.000$

Torsional deflection analysis

Beam is torsion fixed at each end. (as defined in SCI-P-057 section 2.1.6)
 Maximum torque (at supports) $T_o = T_q / 2 = 8.40 \text{ kNm}$

 Tedds BDP 11 Ducie Street Manchester	Project <i>Irwell House</i>		Job no.	
	Calcs for <i>Polytunnel Supporting Beam</i>		Start page no./Revision <i>PTBDS 2</i>	
	Calcs by <i>J</i>	Calcs date <i>08/03/2013</i>	Checked by	Checked date
		Approved by	Approved date	

Average torque between support & centreline

$$T_{av} = T_o / 2 = 4.20 \text{ kNm}$$

Max. angle of twist (at midspan)

$$\phi = T_{av} / (G \times J) \times L / 2 \times 1 \text{ rads} = 0.005 \text{ rads}$$

Section classification

$$b_x / t = 30.3$$

$$d_x / t = 30.3$$

$$b_y / t = 30.3$$

$$d_y / t = 30.3$$

$$r_{1sx} = \min(1.0, \max(-1.0, F_c / (2 \times d_x \times t \times p_{yw}))) = 0.000$$

$$r_{1sy} = \min(1.0, \max(-1.0, F_c / (2 \times d_y \times t \times p_{yw}))) = 0.000$$

$$r_{2s} = F_c / (A_g \times p_{yw}) = 0.000$$

Section classification is semi-compact

Shear capacity (parallel to y-axis)

Design shear force

$$F_{vy} = 6.2 \text{ kN}$$

Design shear resistance (Cl. 4.2.3)

$$P_{vy} = 0.6 \times p_y \times A_{vy} = 491.8 \text{ kN}$$

Pass - Shear

Moment capacity (x-axis)

Design bending moment

$$M_x = 24.8 \text{ kNm}$$

Moment capacity

$$M_{cxu} = p_y \times Z_x = 102.4 \text{ kNm}$$

Moment capacity low shear (Cl. 4.2.5.1)

$$M_{cx} = \min(p_y \times Z_x, 1.2 \times p_y \times Z_x) = 102.4 \text{ kNm}$$

Pass - Moment capacity exceeds design bending moment

Lateral torsional buckling

LT buckling check not required for this section (cl. 4.6.3.1)

Buckling resistance moment

$$M_b = M_{cx} = 102.4 \text{ kNm}$$

LT buckling check not required for this section

Buckling under combined bending & torsion - SCI-P-057 section 2.3

For simplicity, a conservative check is applied using the maximum stresses due to each of the separate load effects, even though these do not necessarily all occur at the same section along the member.

Maximum angle of twist

$$\phi = 0.005 \text{ rads}$$

Induced minor axis moment

$$M_{yt} = M_x \times \phi / 1 \text{ rad} = 0.12 \text{ kNm}$$

Normal stress at corner due to M_{yt}

$$\sigma_{byt} = M_{yt} / Z_y = 0 \text{ N/mm}^2$$

Interaction index

$$i_b = M_x \times m_{LT} / M_b + \sigma_{byt} / p_y \times (1 + 0.5 \times M_x \times m_{LT} / M_b) = 0.24$$

Pass - Combined bending and torsion check satisfied

Local capacity under combined bending & torsion

For simplicity, a conservative check is applied using the maximum stresses due to each of the separate load effects, even though these do not necessarily all occur at the same section along the member.

Max. direct stress due to M_x

$$\sigma_{bx} = M_x / Z_x = 86 \text{ N/mm}^2$$

Combined stress - eqn 2.22

$$\sigma_{bx} + \sigma_{byt} = 86 \text{ N/mm}^2$$

Design strength

$$p_y = 355 \text{ N/mm}^2$$

Pass - Local capacity

Combined shear stresses SCI-P-057 section 2.3

For simplicity, a conservative check is applied using the maximum shear stresses due to each of the separate load effects, even though these do not necessarily all occur at the same section along the member.

Max. shear stress due to bending

$$\tau_{bw} = F_{vy} \times Q_w / (I_x \times 2 \times t) = 3 \text{ N/mm}^2$$

Max. shear stresses due to torsion

$$\tau_t = T_o / C = 20 \text{ N/mm}^2$$

Amplified shear stress due to torsion

$$\tau_{vt} = \tau_t \times (1 + 0.5 \times M_x \times m_{LT} / M_b) = 22 \text{ N/mm}^2$$

 Tedds BDP 11 Ducie Street Manchester	Project <i>Irwell House</i>				Job no.	
	Calcs for <i>Polytunnel Supporting Beam</i>				Start page no./Revision <i>PTB 06 6</i>	
	Calcs by <i>J</i>	Calcs date <i>08/03/2013</i>	Checked by	Checked date	Approved by	Approved date

Combined shear due to bending & torsion

$$\tau = \tau_{bw} + \tau_{vt} = 25 \text{ N/mm}^2$$

Shear strength

$$p_v = 0.6 \times p_y = 213 \text{ N/mm}^2$$

Pass - Combined shear stresses

Twist check

Total applied torque (unfactored)

$$T_{qu} = 12.00 \text{ kNm}$$

Maximum twist under sls loading

$$\phi_{sls} = \phi \times T_{qu} / T_q = 0.20 \text{ deg}$$

Twist limit

$$\phi_{lim} = 2.50 \text{ deg}$$

Pass - Twist

Deflection

Maximum y-axis deflection (from earlier calcs)

$$\delta_{y_max} = 24.0 \text{ mm}$$

Deflection limit - cl. 2.5.2

$$\delta_{lim} = \min(L / k_s, \delta_{lim_abs}) = 32.0 \text{ mm}$$

Pass - Deflection within specified limit

4.0 Second Floor Loading

Same beam loading capacity assessment approach as for roof level.

For the existing imposed load, we allowed for 50kg/sq.ft (2.4KN/m²) according to BS449 1984 Table 5.6, as it is the minimum non domestic occupancy allowance.

For the proposed imposed floor load, we proposed to have an allowance of 1.5KN/m². Taking an average person weight of 80kg, this would allow 45 people in one bay (4m x 6m) at one time.

During the preparation of this calculation package, the beam to column connection has been exposed for inspection. It was a simple angle cleat connection and it was not possible to prove the connection was within loading capacity for the existing load. Therefore we propose to install a 10mm thick stiffness plate to the angle cleat to increase its connection capacity.

Table 5.6 Imposed loads from BS449 1948

Class of loading	Floor space occupancy	Superimposed floor load per sq.ft.	Minimum* loads on slabs or floor boards per ft. width, uniformly distributed	Minimum* load on beams uniformly distributed
I	Private dwellings of not more than two storeys	30	240	1920
II	Rooms in private dwellings of more than two storeys, including flats; hospital rooms and wards; bedrooms and private sitting rooms in hotels and tenement houses; and similar occupancies	40	320	2560
III	Rooms used as offices	50	400	3200
IV	Classrooms in schools and colleges; minimum for light workshops	60	480	3840
V	Banking halls and offices where the public may congregate	70	560	4480
VI	Retail shops; places of assembly with fixed seating†; churches and chapels; restaurants; garages for vehicles not exceeding 2½ tons gross weight (private cars, light vans, etc.); circulation space in machinery halls, power stations, pumping stations etc., where not occupied by plant or equipment	80	640	5120
VII	Places of assembly without fixed seating (public rooms in hotels, dance halls, etc.); minimum for filing or record rooms in offices; light, workshops generally, including light machinery	100	800	6400
VIII	Garages to take all types of vehicles	100	Worst combination of actual wheel loads or, if the slab is capable of effective lateral distribution of load, 1.5 x maximum wheel load, but not less than 2000 lb, considered to be distributed over a floor area 2 ft.6 in. square.	
IX	Light storage space in commercial and industrial buildings; medium workshops	150	—	—
X	Minimum for warehouses and general storage space in commercial and industrial buildings; heavy workshops. (The loads imposed by heavy plant and machinery should be determined and allowed for.)	200	—	—

* Minimum load for slabs becomes operative at spans of less than 8 ft. Minimum load for beams becomes operative on areas less than 64 sq. ft. Beams, ribs and joists spaced at not more than 3 ft. centres may be calculated for slab loadings.

The loadings stated in these columns refer to the design of the slabs and individual beams respectively, including their connections.

† Fixed seating implies that the removal of the seating and the use of the space for other purposes are improbable.

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading.	SFL 01
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
BS449 1948 Table 5.6 Class III	<u>Beam B1</u>	
	beam length = 6m. load width = 4m	
	<u>Existing load</u>	
	Dead = 5 kN/m ² 5 x 4 = 20 kN/m	
	Imposed = ^{minimum} 2.4 kN/m ² 2.4 x 4 = 9.6 kN/m	
	<u>Bending Moment</u>	
	$M = \frac{wl^2}{8} = \frac{(20+9.6) \times 6^2}{8} = 133.2 \text{ kNm}$	M = 133.2 kNm.
	<u>Beam Reaction</u>	
	$V = \frac{wl}{2} = \frac{29.6 \times 6}{2} = 88.8 \text{ kN}$	V = 88.8 kN.
	<u>Proposed load</u>	
	Dead = 5 kN/m ² 5 x 4 = 20 kN/m	
	Imposed = ^{proposed} 1.5 kN/m ² 1.5 x 4 = 6 kN/m	
	Add. wL = 5.6 kN/m	
	<u>Bending Moment</u>	
	$M = \frac{wl^2}{8} = \frac{(20+6+5.6) \times 6^2}{8} = 142.2 \text{ kNm}$	M = 142.2 kNm
	<u>Beam Reaction</u>	
	$V = \frac{wl}{2} = \frac{31.6 \times 6}{2} = 94.8 \text{ kN}$	V = 94.8 kN.

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second floor Loading	SFL 02
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Beam B2</u></p> <p>beam length = 6m load width = 4m</p> <p><u>Existing load</u></p> <p>Same as B1 $\therefore M = 133.2 \text{ kNm}$ $M = 133.2 \text{ kNm}$</p> <p>$V = 88.8 \text{ kN}$ $V = 88.8 \text{ kN}$</p>	
	<p><u>Proposed load</u></p> <p>Dead = $5 \text{ kN/m}^2 \times 4 \text{ m} = 20 \text{ kN/m}$</p> <p>Imposed = $1.5 \text{ kN/m}^2 \times 4 \text{ m} = 6 \text{ kN/m}$</p> <p><u>Bending moment</u></p> <p>$BM = \frac{wl^2}{8} = \frac{26 \times 6^2}{8} = 117 \text{ kNm}$ $M = 117 \text{ kNm}$</p> <p><u>Beam reaction</u></p> <p>$V = \frac{wl}{2} = \frac{26 \times 6}{2} = 78 \text{ kN}$ $V = 78 \text{ kN}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading	SFL 03
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Beam B3</u></p> <p>Beam length = 8m Supports B2 @ 4m</p> <p>Existing load</p> <p>Dead = $5 \text{ kN/m}^2 \times 4 \text{ m} \times 6 \text{ m} = 120 \text{ kN}$</p> <p>Imposed = $2.4 \text{ kN/m}^2 \times 4 \text{ m} \times 6 \text{ m} = 57.6 \text{ kN}$</p> <p>Bending moment</p> <p>BM = $\frac{Pl}{4} = \frac{(120+57.6) \times 8}{4} = 355.2 \text{ kNm}$ M = 355.2 kNm</p> <p>Beam Reaction</p> <p>V = $P/2 = (120+57.6)/2 = 88.8 \text{ kN}$ V = 88.8 kN.</p>	
	<p><u>Proposed load</u></p> <p>Dead = 120 kN @ 4m</p> <p>Imposed = $1.5 \text{ kN/m}^2 \times 4 \text{ m} \times 6 \text{ m} = 36 \text{ kN @ 4m}$</p> <p>Add. uoL = say 34.5 kN / 5.6m = 6.2 kN/m @ 0.9m → 6.5m</p> <p>Bending moment</p> <p>BM = 356.9 kNm</p> <p>Beam reaction</p> <p>V = $R_L = 96.7 \text{ kN}$ $R_R = 94.1 \text{ kN}$</p>	<p>M = 356.9 kNm</p> <p>V = 96.7 kN L 94.1 kN R.</p>

15.15

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second floor Loading	SFL 05
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

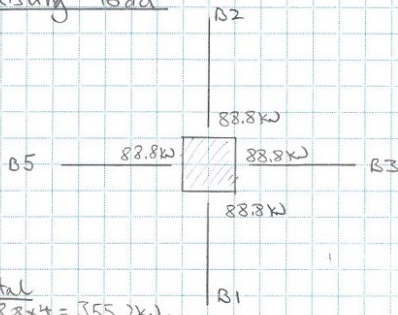
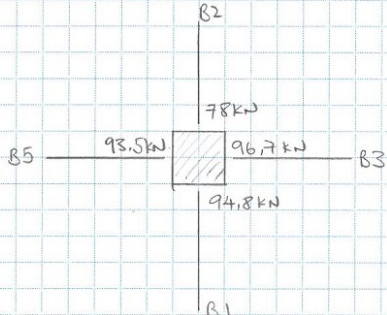
REFERENCE	CALCULATIONS	OUTPUT
	<u>Beam B5</u> beam length = 8m Supports B+C @ 4m. Existing load same as B3 ∴ $M = 355.2 \text{ kNm}$ $V = 88.8 \text{ kN}$	$M = 355.2 \text{ kNm}$ $V = 88.8 \text{ kN}$
	<u>Proposed load</u> Dead = 120 kN @ 4m Imposed = 36 kN @ 4m Add. P = 7.5 kN/2 @ 4m. Add. wDL = 3.4 kN/m	
	<u>Bending moment</u> $BM = \frac{Pl}{4} + \frac{wl^2}{8} = \frac{(120+36+3.75) \times 8}{4} + \frac{3.4 \times 8^2}{8}$ $= 319.5 + 27.2 = 346.7 \text{ kNm}$	$M = 346.7 \text{ kNm}$
	<u>Beam reaction</u> $V = \frac{Pl}{2} + \frac{wl}{2} = \frac{(120+36+3.75)}{2} + \frac{3.4 \times 8}{2} = 93.5 \text{ kN}$	$V = 93.5 \text{ kN}$

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading	SFL 06
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Column C1</u></p> <p><u>Existing load</u></p>  <p>total $88.8 \times 4 = 355.2 \text{ kW}$</p> <p><u>Proposed load</u></p>  <p>total $78 + 96.7 + 94.8 + 93.5$ $= 363 \text{ kW}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading	SFL07
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

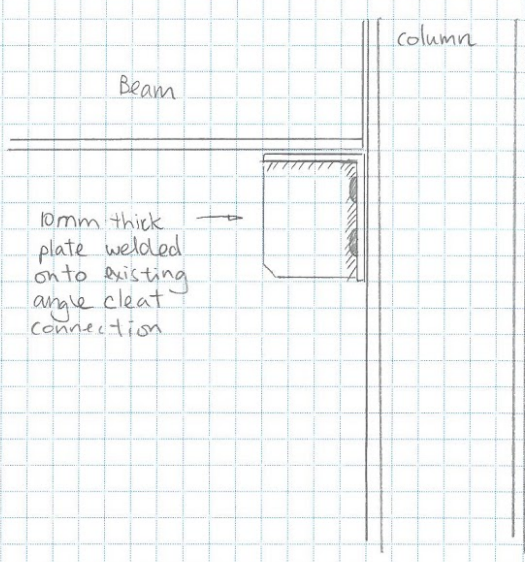
REFERENCE	CALCULATIONS				OUTPUT
<div> <div>Summary</div> <div>Existing load VS Propose load</div> </div>					
		Existing	Propose	Difference	
Beam B1	BM	133.2 kNm	142.2 kNm	+6.8%	
	V	88.8 kN	94.8 kN	+6.8%	
Beam B2	BM	133.2 kNm	117 kNm	-12.2%	
	V	88.8 kN	78 kN	-12.2%	
Beam B3	BM	355.2 kNm	356.9 kNm	+0.5%	
	V	88.8 kN	96.7 kN	+8.9%	
Beam B4	BM	133.2 kNm	128.25 kNm	-3.7%	
	V	88.8 kN	81.75 kN	-7.9%	
Beam B5	BM	355.2 kNm	346.7 kNm	-2.4%	
	V	88.8 kN	93.5 kN	+5.3%	
Column C1	Fx	355.2 kN	363 kN	+2.2%	
All beams are within acceptable loading allowance.					

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Second Floor Loading	SFL08
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Propose Beam to Column Stiffening</u></p>  <p>Stiffen connection is needed to reassure propose beam loadings can be transfered on to the columns.</p>	

5.0 Wind Load

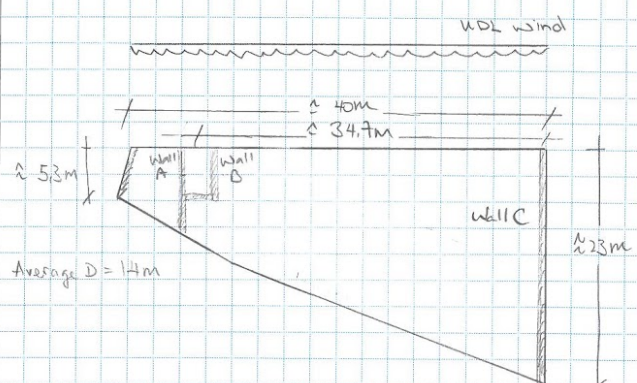
With the proposed 52ft long polytunnel at roof level, this would increase the pickup of wind load and increase loadings apply to top of shear walls.

In this section calculation is done to check if the overturning effect of the shear walls is acceptable with the increased wind load.

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER		
Irwell House.			
ELEMENT	CALC SHEET NUMBER		
Wind load - Existing Condition	PTW 01		
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	 <p>height of building = 10.5m</p> <p>wind load calculation to BS 6399-2</p>	
Table 1	$k_b = 1$	
Fig 3	$H = 10.5$ $\therefore C_r = 0.02$	
2.2.2.1	site wind speed $v_s = v_b \times S_a \times S_d \times S_s \times S_p$	
Fig 6	@ Manchester basic wind speed $v_b = 23 \text{ m/s}$	$v_b = 23 \text{ m/s}$
2.2.2.2	altitude factor $S_a = 1 + 0.001 A_s$	
	$A_s = \text{site altitude} = 28 \text{ m (Google Earth)}$	
	$S_a = 1 + 0.001 \times 28 = 1.028$	$S_a = 1.028$
2.2.2.3	direction factor $S_d = 1$ (ignore building orientation)	$S_d = 1$

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Existing Condition	PTW 02
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT																				
2.2.2.4	seasonal factor $S_s = 1$ permanent	$S_s = 1$																				
2.2.2.5	probability factor $S_p = 1$	$S_p = 1$																				
	$\therefore V_S = 23 \times 1.028 \times 1 \times 1 \times 1$ $= 23.6 \text{ m/s}$	$V_S = 23.6 \text{ m/s}$																				
2.2.3.1	effective wind speed $V_e = V_S \times S_b$																					
2.2.3.3	terrain and building factor S_b																					
Table 4	$H_e = 10.5 \text{ m}$ in town closest distance to sea = 50 km																					
	<table><tr><td></td><td colspan="3">km</td></tr><tr><td>H_e</td><td>10</td><td>50</td><td>100</td></tr><tr><td>10</td><td>1.68</td><td>1.63</td><td>1.58</td></tr><tr><td>10.5</td><td></td><td><u>1.64</u></td><td></td></tr><tr><td>15</td><td>1.82</td><td>1.765</td><td>1.71</td></tr></table>		km			H_e	10	50	100	10	1.68	1.63	1.58	10.5		<u>1.64</u>		15	1.82	1.765	1.71	
	km																					
H_e	10	50	100																			
10	1.68	1.63	1.58																			
10.5		<u>1.64</u>																				
15	1.82	1.765	1.71																			
	$\therefore V_e = 23.6 \times 1.64 = 38.7 \text{ m/s}$	$V_e = 38.7 \text{ m/s}$																				
2.1.2.1	Dynamic Pressure $q_s = 0.613 V_e^2$																					
	$q_s = 0.613 \times 38.7^2 = 903.9 \text{ Pa}$																					
	$1 \text{ Pa} = 1 \text{ N/m}^2 \quad \therefore = 0.9 \text{ kN/m}^2$	$q_s = 0.9 \text{ kN/m}^2$																				

Calculation Sheet

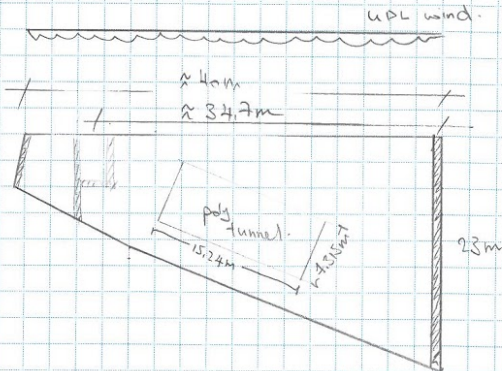
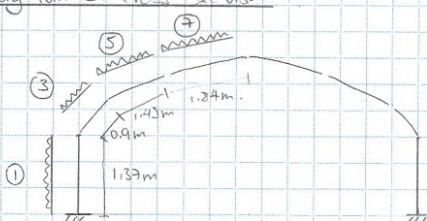
BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Existing Condition	PTW 03
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
2-1.3.1	External surface pressure.	
	$p_e = q_s C_{pe} C_a$	
Fig 4	Diagonal dimension $a =$	
	$a = \sqrt{(40^2 + 10.5^2)} = 41.3$	
	line B $\therefore C_a = 0.84$	
Table S & Fig 12	External pressure coefficient C_{pe}	
	$D/H = 14 / 10.5 = 1.3$	
	$\therefore C_{pe} = 0.775$	
	\therefore wind load on building elevation	
	$= 0.9 \text{ kN/m}^2 \times 0.84 \times 0.775$	
	$= \underline{\underline{0.6 \text{ kN/m}^2}}$	$p_e =$
		$\underline{\underline{0.6 \text{ kN/m}^2}}$

BDP.

REFERENCE	CALCULATIONS	OUTPUT
	 <p>u.p.l. wind.</p> <p>$\approx 4m$</p> <p>$\approx 34.7m$</p> <p>poly tunnel:</p> <p>$15.24m$</p> <p>$4.35m$</p> <p>$23m$</p> <p>Calculate total wind load apply to poly tunnel north elevation.</p> <p>From previous poly tunnel wind calculation.</p> <p><u>Poly tunnel cross section.</u></p>  <p>① = $0.34 \text{ kN/m}^2 \times 1.37m \times 15.24m = 7.1 \text{ kN}$</p> <p>③ = $0.376 \text{ kN/m}^2 \times 0.9m \times 15.24m = 5.2 \text{ kN}$</p> <p>⑤ = $0.141 \text{ kN/m}^2 \times 1.45m \times 15.24m = 3.1 \text{ kN}$</p> <p>⑦ = $0.047 \text{ kN/m}^2 \times 1.84m \times 15.24m = 1.3 \text{ kN}$</p> <p>Total $= 7.1 + 5.2 + 3.1 + 1.3$ $= \underline{\underline{16.7 \text{ kN}}}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 05
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE
HL	March 13

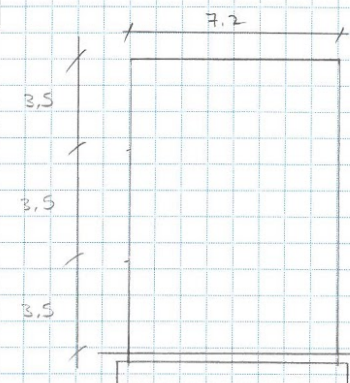
REFERENCE	CALCULATIONS	OUTPUT
	<p>Consider walls A + B as most heavily loaded walls.</p> <p>Wall stiffness.</p> <div> <div> <p>Wall A</p> <p>0.215</p> <p>7.2</p> <p>IA</p> </div> <div> <p>Wall B</p> <p>0.215</p> <p>5</p> <p>IB</p> </div> </div> <p>Brick = 20 kN/m³</p> $I_A = 0.215 \times 7.2^3 / 12 = 6.7 \text{ m}^4$ $I_B = 0.215 \times 5^3 / 12 = 2.2 \text{ m}^4$ <p>∴ wall A takes 75% of load.</p> <p>wall B takes 25% of load</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 06
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

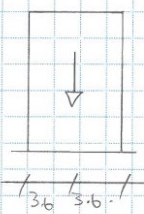
REFERENCE	CALCULATIONS	OUTPUT
	<p>Wind load to wall A. wind load width = 18m</p>  <p>Existing Propose.</p> <p> $W = 0.6 \times 1.75 \times 18 \times 0.75 = 14 \text{ kN.}$ $W = (0.6 \times 1.75 \times 18 + 9) \times 0.75 = 21 \text{ kN.}$ </p> <p> $W = 0.6 \times 3.5 \times 18 \times 0.75 = 28.4 \text{ kN.}$ $W = 28.4 \text{ kN.}$ </p> <p> $W = 28.4 \text{ kN.}$ $W = 28.4 \text{ kN.}$ </p> <p>Existing load Moment</p> <p> $M = 28.4 \times 3.5 + 28.4 \times 7 + 14 \times 10.5$ $= 445.2 \text{ kNm.}$ </p> <p>Propose load Moment</p> <p> $M = 28.4 \times 3.5 + 28.4 \times 7 + 21 \times 10.5$ $= 518.7 \text{ kNm.}$ </p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW07
DRAWING REF	

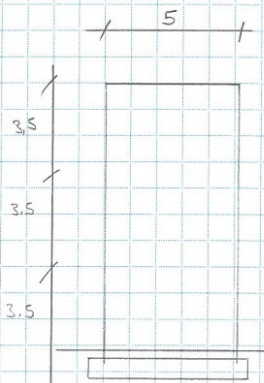
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Wall A resisting moment.</u></p> <p><u>Wall A Dead load.</u></p> <p>Self weight = $20 \times 0.215 \times 10.5 \times 7.2$ $= 325 \text{ kN.}$</p> <p>Slab load = load area = $2\text{m} \times 7.2\text{m} = 14.4\text{m}^2$ $= 5 \text{ kN/m}^2 \times 14.4\text{m}^2$ $= 72 \text{ kN. per floor.}$</p> <p>total slab = 72×3 $= 216 \text{ kN.}$</p> <p>Total = $325 + 216 = 541 \text{ kN.}$</p> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> $M = 541 \times 7.2 / 4$ $= 973.8 \text{ kNm.}$ </div> </div> <p>Existing safety factor = $973.8 / 445.2$ load = 2.2</p> <p>Propose safety factor = $973.8 / 518.7$ load = 1.9</p>	

Calculation Sheet

BDP.

JOB TITLE		JOB NUMBER	
Irwell House			
ELEMENT		CALC SHEET NUMBER	
Wind load - Resistance		PTW 08	
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

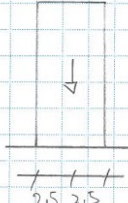
REFERENCE	CALCULATIONS	OUTPUT
	<p>Wind load to wall B</p>  <p>Existing</p> <p>Propose</p> <p>Wind load width = 18m</p> <p>Existing</p> <p>Propose</p> <p>Existing</p> <p>Propose</p> <p>Existing</p> <p>Propose</p> <p>Existing load moment</p> <p>Propose load moment</p>	

Calculation Sheet

BDP.

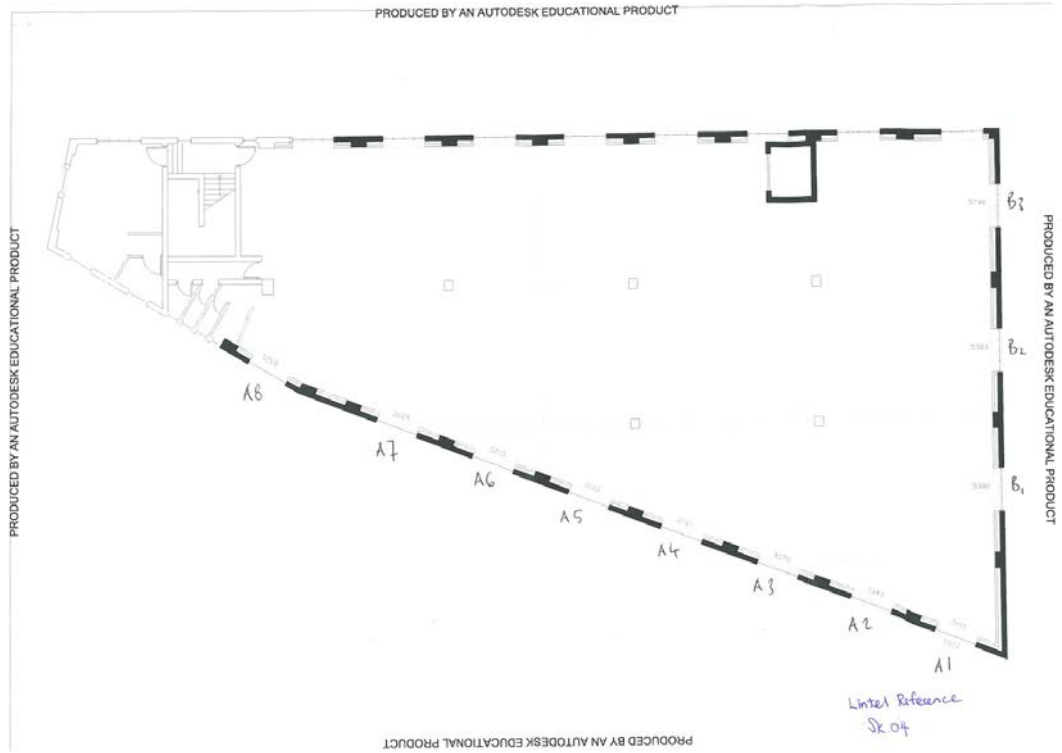
JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 09
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Wall B resisting moment</u></p> <p><u>Wall B Dead load</u></p> <p>selfweight = $20 \times 0.215 \times 10.5 \times 5$ $= 225.75 \text{ kN}$</p> <p>slab = $5 \text{ kN/m}^2 \times 0.6 \times 5 \times 3 = 45 \text{ kN}$ stair = $3 \text{ kN/m}^2 \times 1 \times 2.5 \times 2 = 15 \text{ kN}$</p>  <p>$M = 285.8 \times 5 / 4$ $= 357 \text{ kNm}$</p> <p>Existing safety factor = $357 / 149.1$ load = 2.4</p> <p>Propose safety factor = $357 / 173.3$ load = 2.1</p>	

6.0 Lintel Design

As the existing lintels are damaged, new lintels are needed for replacement.

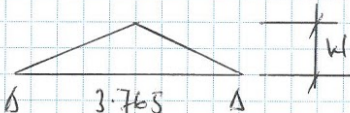


Calculation Sheet

BDP.

JOB TITLE	IRWELL HOUSE	JOB NUMBER	
ELEMENT	LINTEL TYPE A	CALC SHEET NUMBER	A1
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
			3/2013

REFERENCE	CALCULATIONS	OUTPUT
	<p>Max span = 3.765 m (A1 to A8) (inside face of piers)</p> <p>$G_u = 5 \text{ kN/m}^2$</p> <p>$Q_u = 0.6 + 0.2 = 0.8 \text{ kN/m}^2$</p>  <p>$W = (1.4 \cdot 5.0 \cdot 0.93) + (1.6 \cdot 0.8 \cdot 0.93)$ $= 7.70 \text{ kN/m}$</p> <p>Also consider wt. of brickwork over</p> <p>$\therefore \text{Allow } W = 18 \cdot 0.215 \cdot 0.75 = 3.0 \text{ kN/m}$ $\times 1.4$ $= 4.2 \text{ kN/m}$</p> <p>$M = \frac{7.70 \cdot 3.765^2}{12} + \frac{4.2 \cdot 3.765^2}{8}$ $= 9.1 + 7.4 = 16.5 \text{ kNm}$</p>	

Calculation Sheet

BDP.

JOB TITLE	16mm WARE		
JOB NUMBER			
ELEMENT	LINTER TYPE A		A2
CALC SHEET NUMBER			
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JA	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	$P_v = \frac{7.70 \cdot 3.765}{4} + \frac{4.2 \cdot 3.765}{2}$ $= 15.2 \text{ kN} \quad (\text{factored})$	
	$\text{Unfactored Reaction} = \frac{15.2}{1.4} = 10.9 \text{ kN}$ <p>(for Anchor fixing)</p>	
	<p>try 150 x 90 PRC</p> <p>for $L_E = 3.7\text{m}$ $M_b = 32 \text{ kNm}$</p>	
	$\delta_{max} = \left[\frac{WL^4}{120 EI} + \frac{5WL^4}{384 EI} \right] / 1.4$ $= \left[\frac{7.70 \cdot 3.765^4 \times 10^3}{120 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} + \frac{5 \cdot 4.2 \cdot 3.765^4 \times 10^3}{384 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} \right] / 1.4$	

Calculation Sheet

BDP.

JOB TITLE	IRWILL WASTE			JOB NUMBER	
ELEMENT	LINTER TYPE A			CALC SHEET NUMBER	A3/REV A
DRAWING REF					
CHECKED BY	DATE	CALCULATIONS BY	DATE		
		JR	3/2013		

REFERENCE	CALCULATIONS	OUTPUT
	$= \left[5.4 + 4.6 \right] / 1.4 = 7.1 \text{ mm}$ $= \text{span} / 530$ <p>\therefore USE <u>150 x 90 PFC</u></p> <p>Support fixings:</p> <p>(Assuming 3 bolts in a row vertically at 160 c/c)</p> $F_v = 3 \times 6.1 = 18.3 \text{ kN} > 10.9 \text{ kN}$ <p>\therefore USE <u>3 NO. M12 RAWLOK BOLTS</u></p>	OK✓

Calculation Sheet

BDP.

JOB TITLE	12 WELL HOUSE, SALFORD		
JOB NUMBER			
ELEMENT	LINTEL TYPE A	CALC SHEET NUMBER	A4/leva
DRAWING REF			

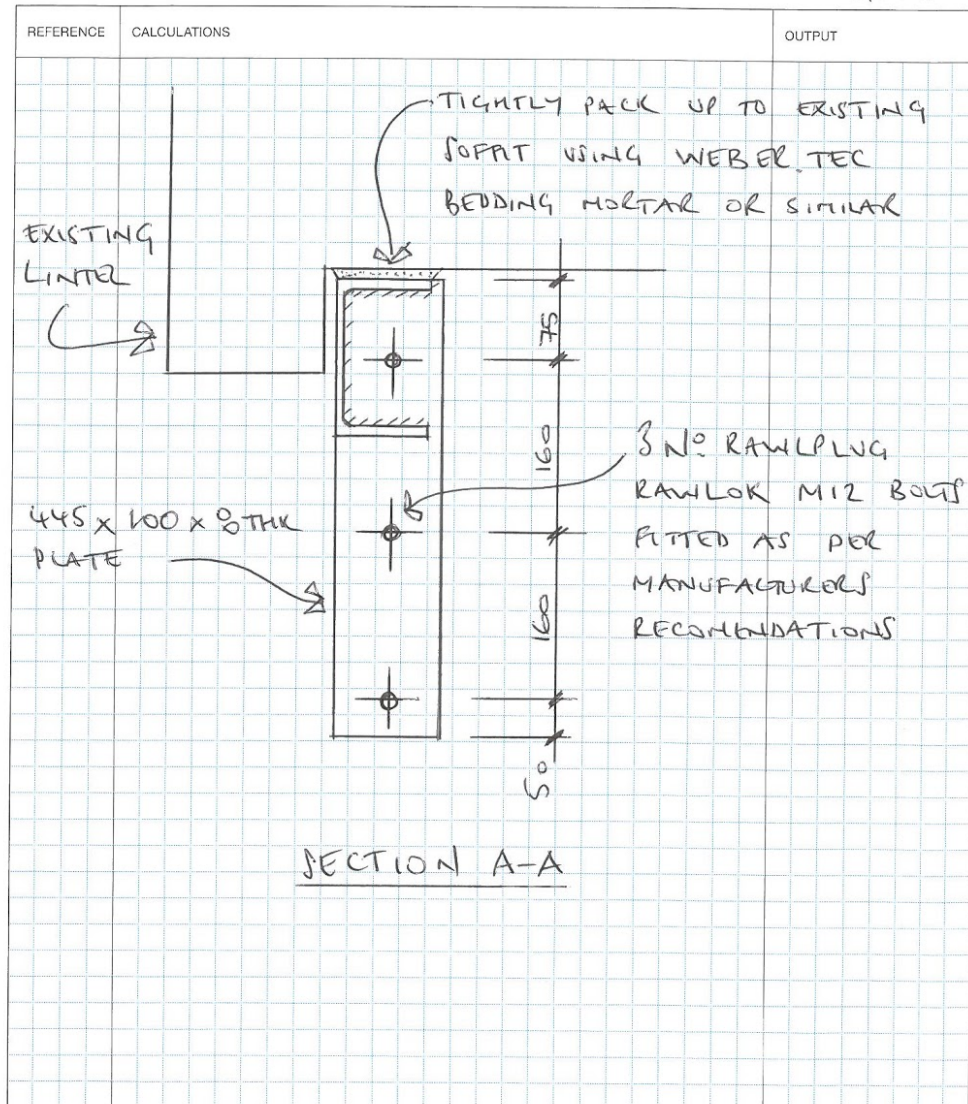
CHECKED BY	DATE	CALCULATIONS BY	DATE
		<i>[Signature]</i>	27/02/2013

REFERENCE	CALCULATIONS	OUTPUT
		<p>ELEVATION - LINTEL TYPE A</p>

Calculation Sheet

BDP.

JOB TITLE	12 WELL WASTE			JOB NUMBER	
ELEMENT	LIMTEL TYPE A			CALC SHEET NUMBER	
DRAWING REF					AS/RVA
CHECKED BY	DATE	CALCULATIONS BY	DATE		
		JR	3/2013		

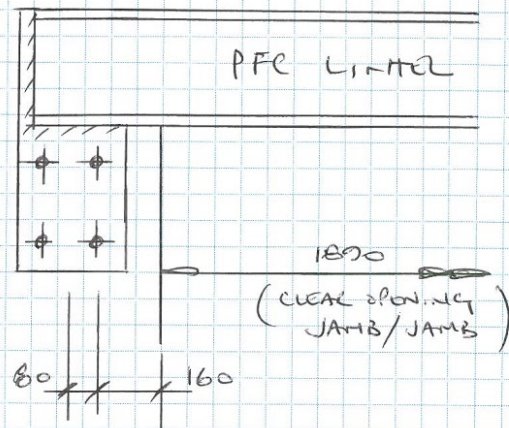
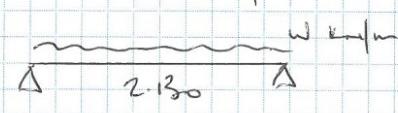


Calculation Sheet

BDP.

JOB TITLE	IRWILL HOUSE	JOB NUMBER	
ELEMENT	LINTER TYPE B	CALC SHEET NUMBER	51
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JF	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>LINTER TYPE B</u></p>  <p>Assuming 4 bolt connection detail</p> <p>PFC Span = $1.89 + 0.16 + 0.08$ $= 2.130 \text{ m}$</p> <p>$G_u = 5 \text{ kN/m}^2$</p> <p>$Q_u = \text{say } 1.5 \text{ kN/m}^2$</p> 	

Calculation Sheet

BDP.

JOB TITLE	12W22 HOSE		
JOB NUMBER			
ELEMENT	UNITED TYPE B	CALC SHEET NUMBER	82
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		AK	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	$w = (1.4 \cdot 5.0 \cdot 2.0)$ $+ (1.6 \cdot 1.5 \cdot 2.0)$ $+ (1.4 \cdot 18 \cdot 0.25 \cdot 0.75)$ $= 22.9 \text{ kN/m}$	(14) (4.6) (4.1)
	$M = \frac{22.9 \cdot 2.13^2}{8} = 12.98 \text{ kNm}$	
	by inspection 150 x 90 PFC OK for bending moment.	
	Check deflection:	
	$\delta = \left[\frac{5 \cdot 22.9 \times 2.13^4 \times 10^3}{384 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} \right] / 1.4$ $= 1.84 \text{ mm} \quad \checkmark \text{ OK}$	
	\therefore USE 150 x 90 PFC.	

Calculation Sheet

BDP.

JOB TITLE	12mm waste	JOB NUMBER	
ELEMENT	Lintel type B	CALC SHEET NUMBER	B3
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		<i>[Signature]</i>	3/2018

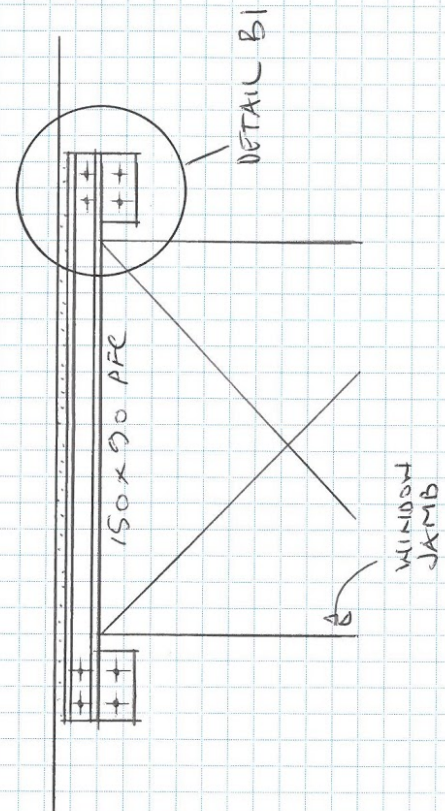
REFERENCE	CALCULATIONS	OUTPUT
	<p>Support Fixings:</p> $F_v = \left(\frac{22.9}{1.4} \right) \cdot \frac{2 \cdot 130}{2} = 17.4 \text{ kN}$ <p>Capacity of 4 N° M12 RAWLOK bolts</p> $= 4 \times 6.1 = 24.4 \text{ kN OK} \checkmark$ <p>\therefore Use <u>4 N° M12 RAWLOK BOLTS.</u></p>	

Calculation Sheet

BDP.

JOB TITLE	ikwal naye	JOB NUMBER	
ELEMENT	Lintel Type B	CALC SHEET NUMBER	84
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JR	3/2013

REFERENCE	CALCULATIONS	OUTPUT
		<p>ELEVATION - Lintel Type B</p>

Calculation Sheet

BDP.

JOB TITLE	1RWall noise	JOB NUMBER	
ELEMENT	Lintel type B	CALC SHEET NUMBER	
DRAWING REF			
CHECKED BY		DATE	
		CALCULATIONS BY	
			DATE

85

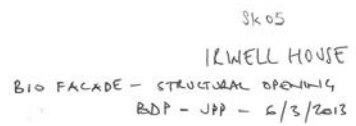
REFERENCE	CALCULATIONS	OUTPUT
	<div><p>4 NO M12 RAWLOK BOLTS BY RAWLPLUG.</p><p>150x30 PFC</p><p>WINDOW JAMB</p><p>135x260x8 PLATE</p><p>75</p><p>160</p><p>50</p><p>110</p><p>50</p><p>160</p><p>50</p></div>	
	<p>DETAIL B1</p>	

Calculation Sheet

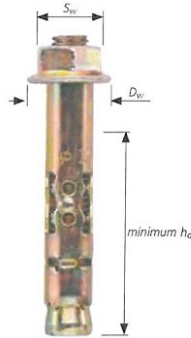
BDP.

JOB TITLE	IRWELL HOJIE		
JOB NUMBER			
ELEMENT	LINTEL TO BIO WALL		BW/1
CALC SHEET NUMBER			
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE

REFERENCE	CALCULATIONS	OUTPUT
	<p>Span = 3.22 m</p> <p>$w = 1.4 \cdot 0.7 \cdot 0.3 \cdot 18 = 5.3 \text{ kN/m}$ (conservative load)</p> <p>$M = \frac{wL^2}{8} = \frac{5.3 \cdot 3.22^2}{8} = 6.89 \text{ kNm}$</p> <p>Try 200 x 100 x 5 RHS on <u>MINOR</u> axis.</p> <p>for 200 x 100 x 5 RHS $M_{cy} = 18.9 \text{ kNm}$ OK ✓</p> <p>Check deflection..</p> <p>$\delta = \frac{5}{384} \frac{wL^4}{EI}$</p> <p>$= \frac{5}{384} \frac{(5.3/1.4) \cdot 3.22^4 \times 10^3}{205 \times 10^6 \cdot 505 \times 10^{-8}}$</p> <p>$= 5.1 \text{ mm}$</p> <p>Allowable $\delta = \text{span} / 250 = 13 \text{ mm}$ OK ✓</p> <p>USE: <u>200 x 100 x 5 RHS (MINOR)</u></p>	



Product Information



DESCRIPTION

The Rawlok® is a torque controlled expansion anchor comprising a split sleeve and a bolt incorporating an expander wedge.

It is a through fixing, thus allowing the hole in the substrate to be drilled through the pre-positioned fixture, eliminating the need for marking out, ensuring fast and simple installation.

SUITABLE FOR USE IN:

Concrete
Brickwork
Blockwork
Stone.

FEATURES

1. Bolt and drill size marked on sleeve to ensure correct installation.
2. Integral collapse feature to ensure maximum clamping force is applied to the fixture.
3. Anchor designed for optimum performance in most base material types.
3. One piece flange nut.

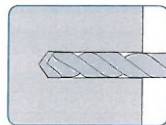
TYPICAL APPLICATIONS

- Stadium seating
- Radiators
- Satellite dishes
- Signs
- Shutters
- Garage doors

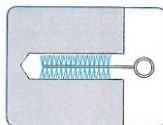
RAWLOK® Bolt Projecting - Zinc plated

BOLT SIZE (G)	BOLT LENGTH (mm) (L)	NUT DIAMETER (mm) (A)	FLANGE DIAMETER (mm) (D _{fl})	MAXIMUM FIXTURE THICKNESS (mm) (T _{fix})	MINIMUM HOLE DEPTH IN STRUCTURE (mm) (h _o)	MINIMUM EFFECTIVE EMBEDMENT DEPTH (mm) (h _{ed})	MINIMUM SUBSTRATE THICKNESS (mm) (t _{min})	HOLE DIAMETER		RECOMMENDED TIGHTENING TORQUE (Nm)				(ZINC PLATED)	
								IN FIXTURE (mm) (d _f)	IN STRUCTURE (mm) (d _s)	CONCRETE 30N/mm ² (T _{res})	BRICKWORK 20.5N/mm ² (T _{res})	BLOCKWORK 14N/mm ² (T _{res})	BLOCKWORK 7N/mm ² (T _{res})	PRODUCT CODE	NEW CODE
M5	56	8	12	25	30	26	50	8	6.5	2.5	2.5	1.5	1.0	69-506	RLK-P-05056
M6	40	10	14	10	35	26	55	10	8	6.0	6.0	3.0	2.0	69-508	RLK-P-06040
	65			35										69-510	RLK-P-06065
M8	50	13	17	10	40	36	65	12	10	11.0	11.0	6.0	4.0	69-514	RLK-P-08050
	75			36										69-516	RLK-P-08075
	95			55										69-518	RLK-P-08095
	60			10										69-520	RLK-P-10060
M10	75	15	21	27	55	43	85	14	12	22.0	22.0	11.0	8.0	69-522	RLK-P-10070
	100			50										69-524	RLK-P-10100
	130			80										69-525	RLK-P-10130
	110			55										69-528	RLK-P-12110
M12	145	18	26	85	60	50	90	18	16	38.0	38.0	25.0	12.0	69-530	RLK-P-12145

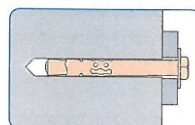
Installation



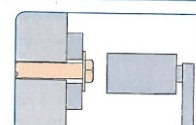
1. Drill a hole of required diameter and depth.
Note: Fixing into mortar joints should be avoided.



2. Remove debris and thoroughly clean hole with brush and pump.



3. Insert Rawlok® Sleeve Anchor through the fixture into the hole.



4. Tighten to recommended torque with torque wrench.

Ex 02

Specification Data

RAWLOK® Bolt Projecting Performance Data

SIZE	CONCRETE, $f_{ck}, cube = 30N/mm^2$ (C20/25)								
	CHARACTERISTIC LOAD (kN)		DESIGN LOAD FACTORED (kN)		RECOMMENDED LOAD UNFACTORED (kN)		CHARACTERISTIC EDGE DISTANCE (mm)		CHARACTERISTIC SPACING (mm)
	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION ($C_{ed,N}$)	SHEAR ($C_{ed,V}$)	TENSION & SHEAR ($C_{ed,N}$) ($C_{ed,V}$)
M5	5.0	3.6	2.3	2.0	1.9	1.9	60	60	60
M6	6.9	5.4	3.2	3.0	2.7	2.5	70	80	80
M8	9.3	9.0	4.3	5.0	3.6	4.2	80	100	100
M10	11.4	12.6	5.3	7.0	4.4	5.8	100	120	120
M12	14.5	19.8	6.7	11.0	5.6	9.2	120	160	160

SIZE	BRICKWORK, $f_{ck} = 20 N/mm^2$						BLOCKWORK, $f_{ck} = 14 N/mm^2$						BLOCKWORK, $f_{ck} = 7 N/mm^2$					
	CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)		CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)		CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)	
	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})
M5	2.4	3.4	1.1	1.9	0.9	1.6	1.9	3.4	0.9	1.9	0.8	1.6	1.5	2.3	0.7	1.3	0.6	1.1
M6	3.7	5.2	1.7	2.9	1.4	2.4	3.2	5.2	1.5	2.9	1.3	2.4	2.4	2.5	1.1	1.4	0.9	1.2
M8	5.0	8.6	2.3	4.8	1.9	4.0	4.5	8.6	2.1	4.8	1.8	4.0	3.5	2.7	1.6	1.5	1.3	1.3
M10	6.0	10.3	2.8	5.7	2.3	4.8	5.6	10.3	2.6	5.7	2.2	4.8	4.5	3.1	2.1	1.7	1.8	1.4
M12	7.3	13.1	3.4	7.3	2.8	6.1	6.9	13.1	3.2	7.3	2.7	6.1	5.8	3.4	2.7	1.9	2.3	1.6

For further explanations on calculations please see pages 10 and 11
When calculating loads in brickwork and blockwork apply the published edge distance and spacing for concrete and assume these figures to be the absolute minimums. Concrete reduction factors must NOT be applied.

Reduction Factors - Edge and Spacing Distances for Rawlok® Sleeve Anchor Bolt Projecting.

The full characteristic edge and spacing distances shown in the table above are the minimum allowable for the quoted DESIGN RESISTANCE or RECOMMENDED LOAD, depending on your design method.

Where these dimensions are not achievable, the appropriate reduction factor/s from the tables below must be applied to the DESIGN RESISTANCE or RECOMMENDED LOAD.
Choose the required bolt diameter across the top of the appropriate table and read down the left hand column until actual edge or spacing distance is found.

Read off the reduction factor where the two lines intersect (interpolate as required).
Multiply this factor by the DESIGN RESISTANCE or RECOMMENDED LOAD quoted in the table.
On the occasion that multiple close edge and/or spacing distances occur, the appropriate reduction factors must be applied.

Edge Distance (Concrete Only)

EDGE (mm)	TENSILE: EDGE REDUCTION FACTORS					EDGE (mm)	SHEAR: EDGE REDUCTION FACTORS				
	M5	M6	M8	M10	M12		M5	M6	M8	M10	M12
40	0.75					40	0.58				
50	0.87	0.79				50	0.79	0.53			
60	1.00	0.89	0.81			60	1.00	0.69	0.50		
70		1.00	0.91	0.77		70		0.84	0.62	0.48	
80			1.00	0.85		80		1.00	0.75	0.58	
90				0.92	0.81	90			0.87	0.69	0.45
100				1.00	0.87	100			1.00	0.79	0.53
120						120				1.00	0.69
140						140					0.84
160						160					1.00

Spacing (Concrete Only)

SPACING (mm)	TENSILE & SHEAR REDUCTION FACTORS				
	M5	M6	M8	M10	M12
40	0.80				
50	0.90	0.77			
60	1.00	0.85	0.76		
70		0.92	0.82	0.75	
80		1.00	0.88	0.80	
90			0.94	0.85	0.74
100			1.00	0.90	0.77
120				1.00	0.85
140					0.92
160					1.00

7.0 Sketches / Extract References

Roof Level Beam Reference	SK01
Beam reactions with proposed loadings	SK02
Second Floor Propose Layout Beam Reference	SK03
Lintel Reference	SK04
B10 Façade – Structural Opening	SK05
Historial Structural Steelwork Handbook –	
Imposed loads from BS449 1948	EX01
Rawlok Bolt Production Information	EX02

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 05
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

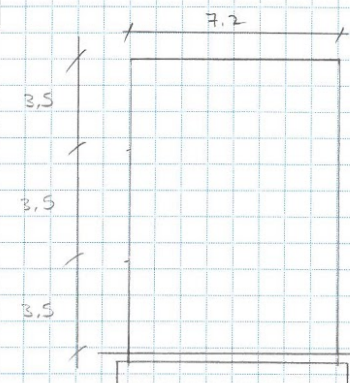
REFERENCE	CALCULATIONS	OUTPUT
	<p>Consider walls A + B as most heavily loaded walls.</p> <p>Wall stiffness.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Wall A</p> <p>0.215</p> <p>7.2</p> <p>IA</p> </div> <div style="text-align: center;"> <p>Wall B</p> <p>0.215</p> <p>5</p> <p>IB</p> </div> </div> <p>Brick = 20 kN/m³</p> $I_A = 0.215 \times 7.2^3 / 12 = 6.7 \text{ m}^4$ $I_B = 0.215 \times 5^3 / 12 = 2.2 \text{ m}^4$ <p>∴ wall A takes 75% of load.</p> <p> wall B takes 25% of load</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 06
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

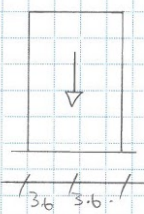
REFERENCE	CALCULATIONS	OUTPUT
	<p>Wind load to wall A. wind load width = 18m</p>  <p>Existing Proposed</p> <p>W = $0.6 \times 1.75 \times 18 \times 0.75 = 14 \text{ kN}$ W = $(0.6 \times 1.75 \times 18 + 9) \times 0.75 = 21 \text{ kN}$</p> <p>W = $0.6 \times 3.5 \times 18 \times 0.75 = 28.4 \text{ kN}$ W = 28.4 kN</p> <p>W = 28.4 kN W = 28.4 kN</p> <p>Existing load Moment</p> <p>M = $28.4 \times 3.5 + 28.4 \times 7 + 14 \times 10.5 = 445.2 \text{ kNm}$</p> <p>Proposed load Moment</p> <p>M = $28.4 \times 3.5 + 28.4 \times 7 + 21 \times 10.5 = 518.7 \text{ kNm}$</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW07
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Wall A resisting moment.</u></p> <p><u>Wall A Dead load.</u></p> <p>Self weight = $20 \times 0.215 \times 10.5 \times 7.2$ $= 325 \text{ kN.}$</p> <p>Slab load = load area = $2m \times 7.2m = 14.4m^2$ $= 5 \text{ kN/m}^2 \times 14.4m^2$ $= 72 \text{ kN. per floor.}$</p> <p>total slab = 72×3 $= 216 \text{ kN.}$</p> <p>Total = $325 + 216 = 541 \text{ kN.}$</p> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> $M = 541 \times 7.2 / 4$ $= 973.8 \text{ kNm.}$ </div> </div> <p>Existing safety factor = $973.8 / 445.2$ load = 2.2</p> <p>Propose safety factor = $973.8 / 518.7$ load = 1.9</p>	

Calculation Sheet

BDP.

JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 08
DRAWING REF	
CHECKED BY	DATE
CALCULATIONS BY	DATE
HL	March 13

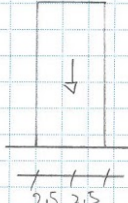
REFERENCE	CALCULATIONS	OUTPUT
	<p>Wind load to wall B wind load width = 18m</p> <p>Existing Propose</p> <p>Top section: $w = 0.6 \times 1.75 \times 18 \times 0.25 = 4.7 \text{ kN}$ $w = (0.6 \times 1.75 \times 18 + 9) \times 0.25 = 7 \text{ kN}$</p> <p>Middle section: $w = 0.6 \times 3.5 \times 18 \times 0.25 = 9.5 \text{ kN}$ $w = 9.5 \text{ kN}$</p> <p>Bottom section: $w = 9.5 \text{ kN}$ $w = 9.5 \text{ kN}$</p> <p>Existing load moment</p> $M = 1.5 \times 3.5 + 9.5 \times 7 + 4.7 \times 10.5 = 149.1 \text{ kNm}$ <p>Propose load moment</p> $M = 9.5 \times 3.5 + 9.5 \times 7 + 7 \times 10.5 = 173.3 \text{ kNm}$	

Calculation Sheet

BDP.

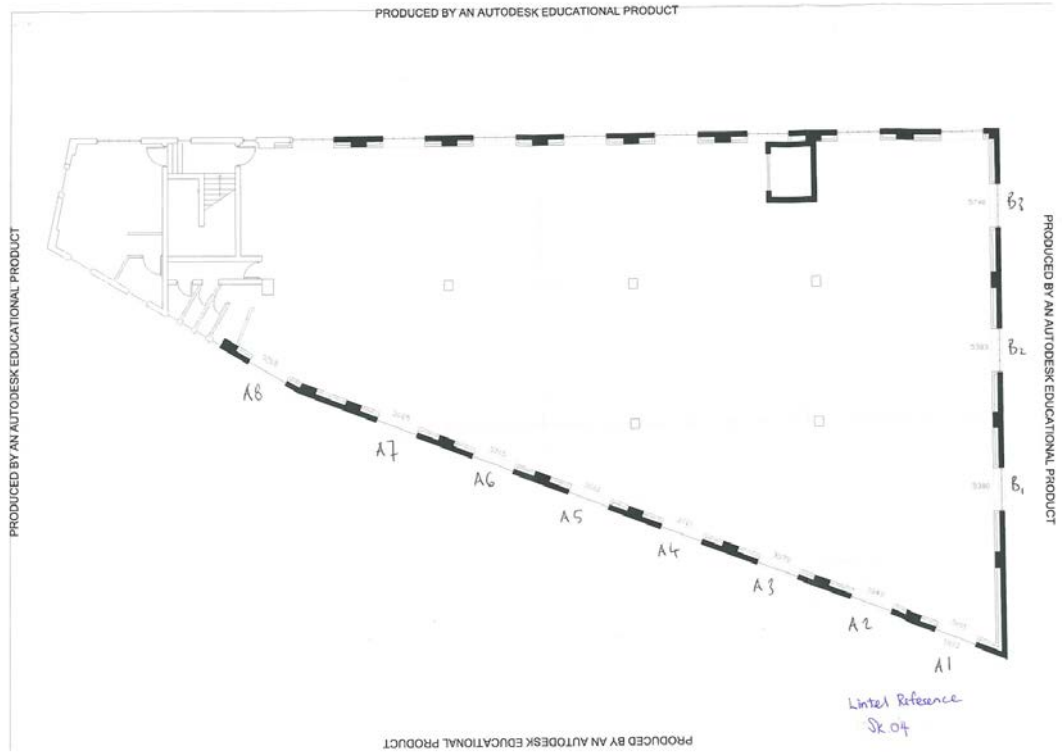
JOB TITLE	JOB NUMBER
Irwell House	
ELEMENT	CALC SHEET NUMBER
Wind load - Resistance	PTW 09
DRAWING REF	

CHECKED BY	DATE	CALCULATIONS BY	DATE
		HL	March 13

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>Wall B resisting moment</u></p> <p><u>Wall B Dead load</u></p> <p>selfweight = $20 \times 0.215 \times 10.5 \times 5$ $= 225.75 \text{ kN}$</p> <p>slab = $5 \text{ kN/m}^2 \times 0.6 \times 5 \times 3 = 45 \text{ kN}$ stair = $.3 \text{ kN/m}^2 \times 1 \times 2.5 \times 2 = 15 \text{ kN}$</p>  <p>$M = 285.8 \times 5 / 4$ $= 357 \text{ kNm}$</p> <p>Existing safety factor = $357 / 149.1$ load = 2.4</p> <p>Propose safety factor = $357 / 173.3$ load = 2.1</p>	

6.0 Lintel Design

As the existing lintels are damaged, new lintels are needed for replacement.

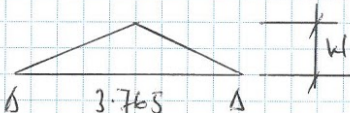


Calculation Sheet

BDP.

JOB TITLE	IRWELL HOUSE	JOB NUMBER	
ELEMENT	LINTEL TYPE A	CALC SHEET NUMBER	A1
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
			3/2013

REFERENCE	CALCULATIONS	OUTPUT
	<p>Max span = 3.765 m (A1 to A8) (inside face of piers)</p> <p>$G_u = 5 \text{ kN/m}^2$</p> <p>$Q_u = 0.6 + 0.2 = 0.8 \text{ kN/m}^2$</p>  <p>$W = (1.4 \cdot 5.0 \cdot 0.93) + (1.6 \cdot 0.8 \cdot 0.93)$ $= 7.70 \text{ kN/m}$</p> <p>Also consider wt. of brickwork over</p> <p>$\therefore \text{Allow } W = 18 \cdot 0.215 \cdot 0.75 = 3.0 \text{ kN/m}$ $\times 1.4$ $= 4.2 \text{ kN/m}$</p> <p>$M = \frac{7.70 \cdot 3.765^2}{12} + \frac{4.2 \cdot 3.765^2}{8}$ $= 9.1 + 7.4 = 16.5 \text{ kNm}$</p>	

Calculation Sheet

BDP.

JOB TITLE	16mm WARE	JOB NUMBER	
ELEMENT	Lintel type A	CALC SHEET NUMBER	A2
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JK	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	$P_v = \frac{7.70 \cdot 1.765}{4} + \frac{4.2 \cdot 3.765}{2}$ $= 15.2 \text{ kN. (factored)}$	
	$\text{Unfactored Reaction} = \frac{15.2}{1.4} = 10.9 \text{ kN.}$ $\text{(for Anchor fixing)}$	
	<p>try 150 x 90 PFC</p> <p>for $L_E = 3.7\text{m}$ $M_b = 32 \text{ kNm.}$</p>	
	$\delta_{max} = \left[\frac{WL^4}{120 EI} + \frac{5WL^4}{384 EI} \right] / 1.4$ $= \left[\frac{7.70 \cdot 3.765^4 \times 10^3}{120 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} + \frac{5 \cdot 4.2 \cdot 3.765^4 \times 10^3}{384 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} \right] / 1.4$	

Calculation Sheet

BDP.

JOB TITLE	IRWILL WASTE			JOB NUMBER	
ELEMENT	LINTER TYPE A			CALC SHEET NUMBER	A3/REV A
DRAWING REF					
CHECKED BY	DATE	CALCULATIONS BY	DATE		
		JR	3/2013		

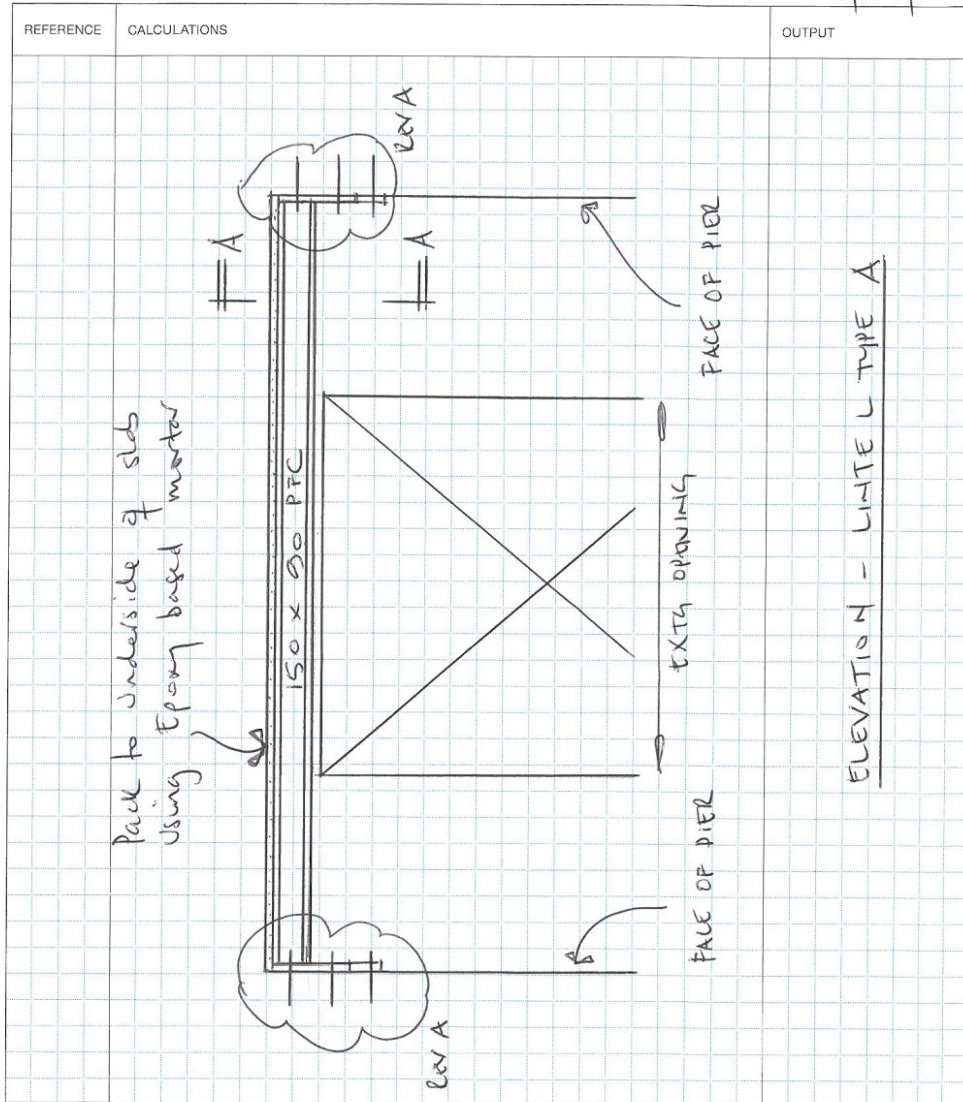
REFERENCE	CALCULATIONS	OUTPUT
	$= \left[5.4 + 4.6 \right] / 1.4 = 7.1 \text{ mm}$ $= \text{span} / 530$ <p>\therefore USE <u>150 x 90 PFC</u></p> <p>Support fixings:</p> <p>(Assuming 3 bolts in a row vertically at 160 c/c)</p> $F_v = 3 \times 6.1 = 18.3 \text{ kN} > 10.9 \text{ kN}$ <p>\therefore USE <u>3 NO. M12 RAWLOK BOLTS</u></p>	OK✓

Calculation Sheet

BDP.

JOB TITLE	12 WALL HOUSE, SALFORD	JOB NUMBER	
ELEMENT	LINTEL TYPE A	CALC SHEET NUMBER	A4/20A
DRAWING REF			

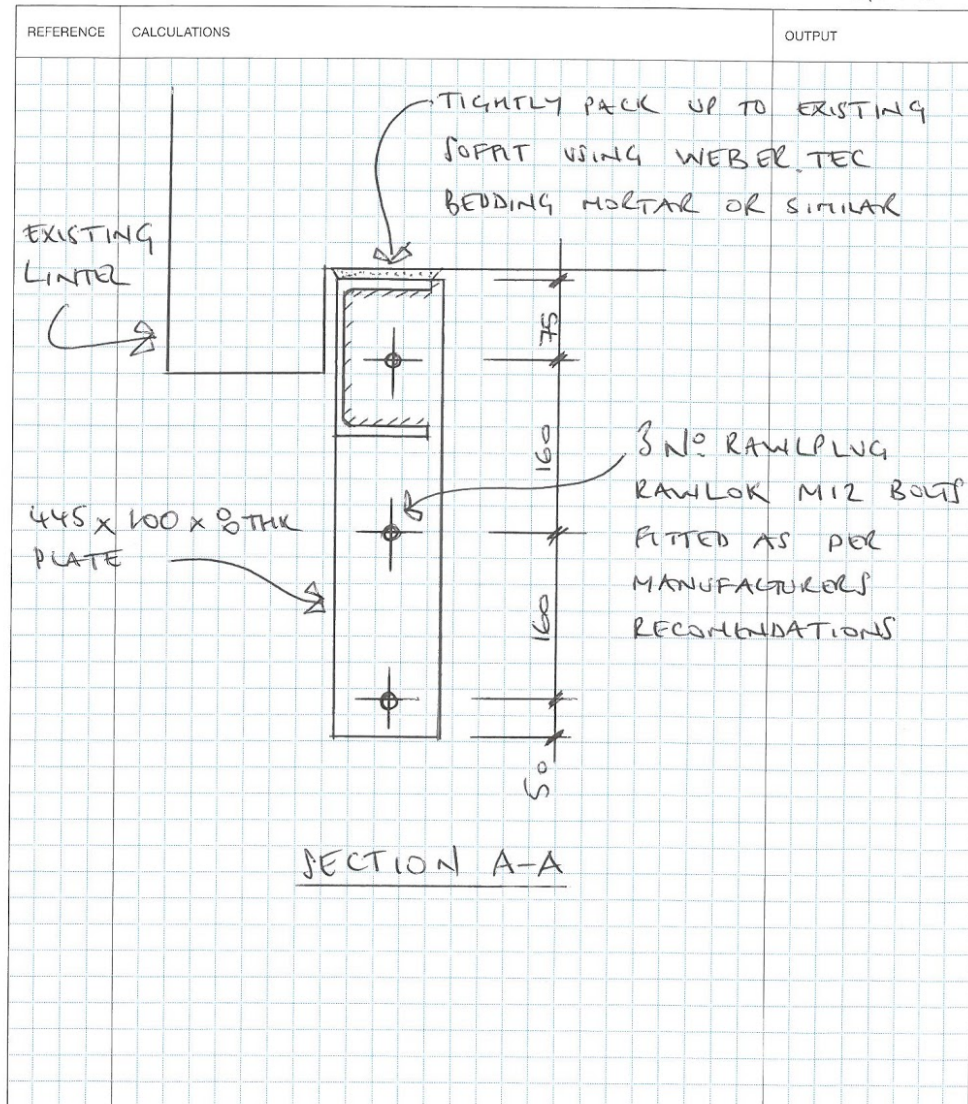
CHECKED BY	DATE	CALCULATIONS BY	DATE
		<i>[Signature]</i>	27/02/2013



Calculation Sheet

BDP.

JOB TITLE	12 WELL WASTE			JOB NUMBER	
ELEMENT	LIMTEL TYPE A			CALC SHEET NUMBER	
DRAWING REF					AS/RVA
CHECKED BY	DATE	CALCULATIONS BY	DATE		
		JR	3/2013		

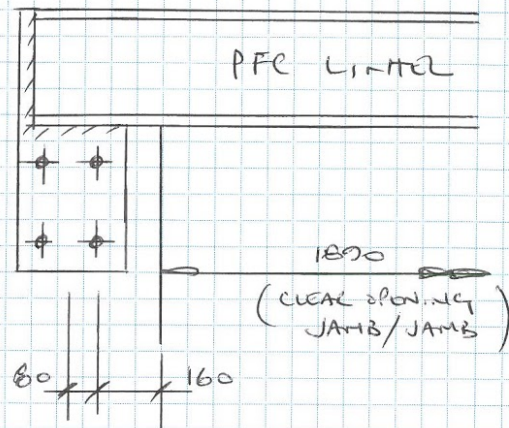
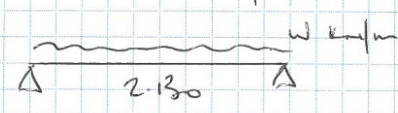


Calculation Sheet

BDP.

JOB TITLE	IRWILL HOUSE	JOB NUMBER	
ELEMENT	LINTER TYPE B	CALC SHEET NUMBER	51
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JF	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	<p><u>LINTER TYPE B</u></p>  <p>Assuming 4 bolt connection detail</p> <p>PFC span = $1.89 + 0.16 + 0.08$ $= 2.130 \text{ m}$</p> <p>$G_u = 5 \text{ kN/m}^2$</p> <p>$Q_u = \text{say } 1.5 \text{ kN/m}^2$</p> 	

Calculation Sheet

BDP.

JOB TITLE	12W22 HOSE	JOB NUMBER	
ELEMENT	WATER TYPE B	CALC SHEET NUMBER	82
DRAWING REF			

CHECKED BY	DATE	CALCULATIONS BY	DATE
		AK	3/2013

REFERENCE	CALCULATIONS	OUTPUT
	$W = (1.4 \cdot 5.0 \cdot 2.0)$ $+ (1.6 \cdot 1.5 \cdot 2.0)$ $+ (1.4 \cdot 18 \cdot 0.25 \cdot 0.75)$ $= 22.9 \text{ kN/m}$	(14) (4.6) (4.1)
	$M = \frac{22.9 \cdot 2.13^2}{8} = 12.98 \text{ kNm}$	
	by inspection 150 x 90 PFC OK for bending moment.	
	Check deflection:	
	$\delta = \left[\frac{5 \cdot 22.9 \times 2.13^4 \times 10^3}{384 \cdot 205 \times 10^6 \cdot 1162 \times 10^{-8}} \right] / 1.4$ $= 1.84 \text{ mm} \quad \checkmark \text{ OK}$	
	\therefore USE 150 x 90 PFC.	

Calculation Sheet

BDP.

JOB TITLE	12mm WISE			JOB NUMBER	
ELEMENT	LIMB TYPE B			CALC SHEET NUMBER	B3
DRAWING REF					

CHECKED BY	DATE	CALCULATIONS BY	DATE
		<i>[Signature]</i>	3/2018

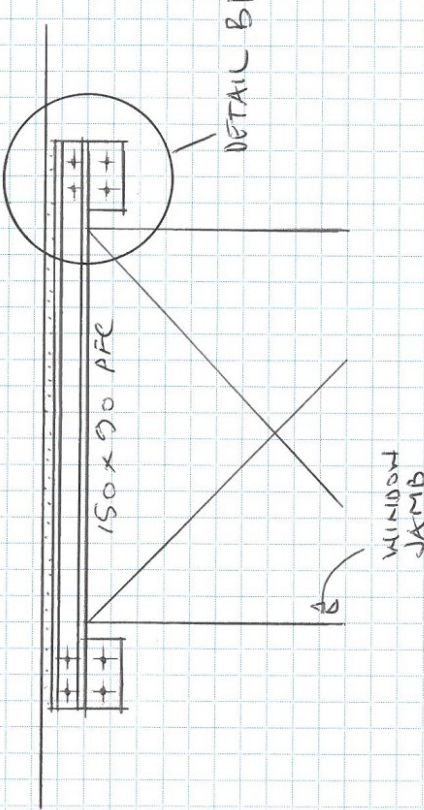
REFERENCE	CALCULATIONS	OUTPUT
	<p>Support Fixings:</p> $F_v = \left(\frac{22.9}{1.4} \right) \cdot \frac{2 \cdot 130}{2} = 17.4 \text{ kN}$ <p>Capacity of 4 N° M12 RAWLOK Bolts</p> $= 4 \times 6.1 = 24.4 \text{ kN OK} \checkmark$ <p>\therefore USE <u>4 N° M12 RAWLOK BOLTS.</u></p>	

Calculation Sheet

BDP.

JOB TITLE	internal window			JOB NUMBER	
ELEMENT	Lintel Type B			CALC SHEET NUMBER	84
DRAWING REF					

CHECKED BY	DATE	CALCULATIONS BY	DATE
		JR	3/2013

REFERENCE	CALCULATIONS	OUTPUT
		<p>ELEVATION - LINTEL TYPE B</p>

Calculation Sheet

BDP.

JOB TITLE	1RWEI WASE	JOB NUMBER	
ELEMENT	LINTEL TYPE B	CALC SHEET NUMBER	
DRAWING REF			
CHECKED BY		DATE	
		CALCULATIONS BY	
			DATE

85

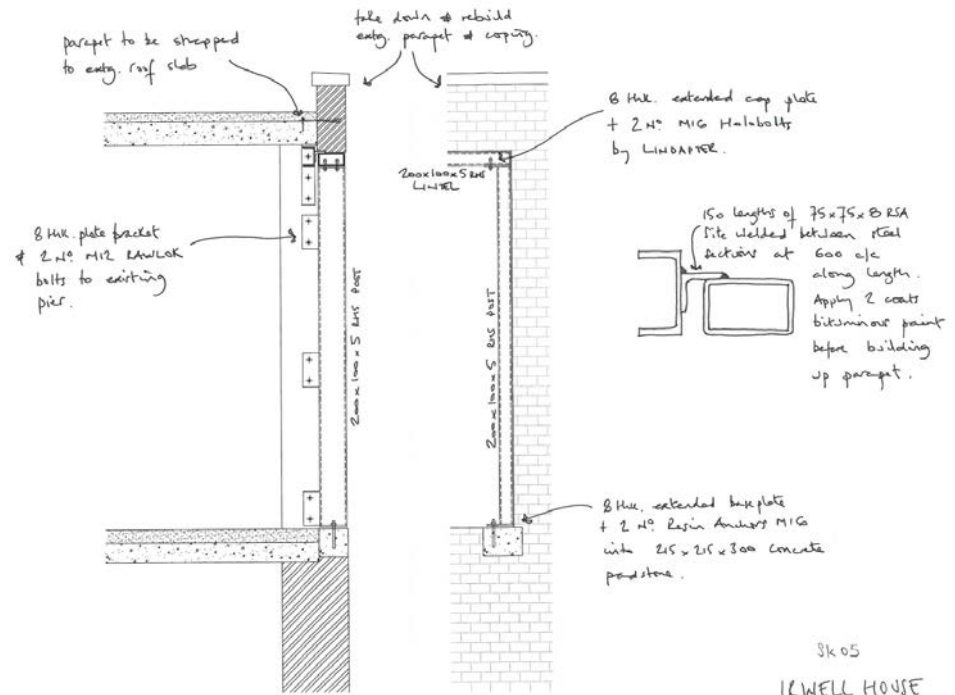
REFERENCE	CALCULATIONS	OUTPUT
	<div><p>4 NO M12 RAWLOK BOLTS BY RAWLPLUG.</p><p>150x30 PFC</p><p>WINDOW JAMB</p><p>135x260x8 PLATE</p><p>DETAIL B1</p></div>	

Calculation Sheet

BDP.

JOB TITLE	IRWELL HOJIE		
JOB NUMBER			
ELEMENT	LINTEL TO BIO WALL		BW/1
CALC SHEET NUMBER			
DRAWING REF			
CHECKED BY	DATE	CALCULATIONS BY	DATE

REFERENCE	CALCULATIONS	OUTPUT
	<p>Span = 3.22 m</p> <p>$w = 1.4 \cdot 0.7 \cdot 0.3 \cdot 18 = 5.3 \text{ kN/m}$ (conservative load)</p> <p>$M = \frac{wL^2}{8} = \frac{5.3 \cdot 3.22^2}{8} = 6.89 \text{ kNm}$</p> <p>Try 200 x 100 x 5 RHS on <u>MINOR</u> axis.</p> <p>for 200 x 100 x 5 RHS $M_{cy} = 18.9 \text{ kNm}$ OK ✓</p> <p>Check deflection..</p> <p>$\delta = \frac{5}{384} \frac{wL^4}{EI}$</p> <p>$= \frac{5}{384} \frac{(5.3/1.4) \cdot 3.22^4 \times 10^3}{205 \times 10^6 \cdot 505 \times 10^{-8}}$</p> <p>$= 5.1 \text{ mm}$</p> <p>Allowable $\delta = \text{span} / 250 = 13 \text{ mm}$ OK ✓</p> <p>USE: <u>200 x 100 x 5 RHS (MINOR)</u></p>	

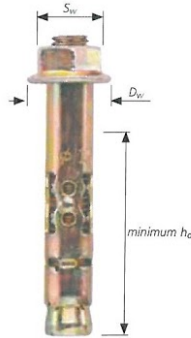


SK05

IRLWELL HOUSE

BIO FACADE - STRUCTURAL OPENING
BDP - JPP - 6/3/2013

Product Information



DESCRIPTION

The Rawlok® is a torque controlled expansion anchor comprising a split sleeve and a bolt incorporating an expander wedge.

It is a through fixing, thus allowing the hole in the substrate to be drilled through the pre-positioned fixture, eliminating the need for marking out, ensuring fast and simple installation.

SUITABLE FOR USE IN:

Concrete
Brickwork
Blockwork
Stone.

FEATURES

1. Bolt and drill size marked on sleeve to ensure correct installation.
2. Integral collapse feature to ensure maximum clamping force is applied to the fixture.
3. Anchor designed for optimum performance in most base material types.
3. One piece flange nut.

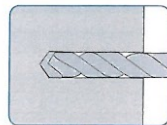
TYPICAL APPLICATIONS

- Stadium seating
- Radiators
- Satellite dishes
- Signs
- Shutters
- Garage doors

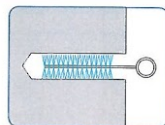
RAWLOK® Bolt Projecting - Zinc plated

BOLT SIZE (G)	BOLT LENGTH (mm) (L)	NUT DIAMETER (mm) (A)	FLANGE DIAMETER (mm) (D _{fl})	MAXIMUM FIXTURE THICKNESS (mm) (T _{fix})	MINIMUM HOLE DEPTH IN STRUCTURE (mm) (h _o)	MINIMUM EFFECTIVE EMBEDMENT DEPTH (mm) (h _{ed})	MINIMUM SUBSTRATE THICKNESS (mm) (t _{min})	HOLE DIAMETER		RECOMMENDED TIGHTENING TORQUE (Nm)				(ZINC PLATED)	
								IN FIXTURE (mm) (d _f)	IN STRUCTURE (mm) (d _s)	CONCRETE 30N/mm ² (T _{res})	BRICKWORK 20.5N/mm ² (T _{res})	BLOCKWORK 14N/mm ² (T _{res})	BLOCKWORK 7N/mm ² (T _{res})		
M5	56	8	12	25	30	26	50	8	6.5	2.5	2.5	1.5	1.0	69-506	RLK-P-05056
M6	40	10	14	10	35	26	55	10	8	6.0	6.0	3.0	2.0	69-508	RLK-P-06040
	65			35										69-510	RLK-P-06065
M8	50	13	17	10	40	36	65	12	10	11.0	11.0	6.0	4.0	69-514	RLK-P-08050
	75			36										69-516	RLK-P-08075
	95			55										69-518	RLK-P-08095
	60			10										69-520	RLK-P-10060
M10	75	15	21	27	55	43	85	14	12	22.0	22.0	11.0	8.0	69-522	RLK-P-10070
	100			50										69-524	RLK-P-10100
	130			80										69-525	RLK-P-10130
	110			55										69-528	RLK-P-12110
M12	145	18	26	85	60	50	90	18	16	38.0	38.0	25.0	12.0	69-530	RLK-P-12145

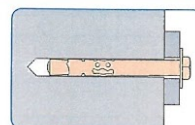
Installation



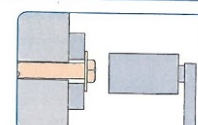
1. Drill a hole of required diameter and depth.
Note: Fixing into mortar joints should be avoided.



2. Remove debris and thoroughly clean hole with brush and pump.



3. Insert Rawlok® Sleeve Anchor through the fixture into the hole.



4. Tighten to recommended torque with torque wrench.

Ex 02

Specification Data

RAWLOK® Bolt Projecting Performance Data

SIZE	CONCRETE, $f_{ck, cube} = 30 \text{ N/mm}^2$ (C20/25)								
	CHARACTERISTIC LOAD (kN)		DESIGN LOAD FACTORED (kN)		RECOMMENDED LOAD UNFACTORED (kN)		CHARACTERISTIC EDGE DISTANCE (mm)		CHARACTERISTIC SPACING (mm)
	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION ($C_{ed,N}$)	SHEAR ($C_{ed,V}$)	TENSION & SHEAR ($S_{ed,N}$ ($S_{ed,V}$))
M5	5.0	3.6	2.3	2.0	1.9	1.9	60	60	60
M6	6.9	5.4	3.2	3.0	2.7	2.5	70	80	80
M8	9.3	9.0	4.3	5.0	3.6	4.2	80	100	100
M10	11.4	12.6	5.3	7.0	4.4	5.8	100	120	120
M12	14.5	19.8	6.7	11.0	5.6	9.2	120	160	160

SIZE	BRICKWORK, $f_{ck} = 20 \text{ N/mm}^2$						BLOCKWORK, $f_{ck} = 14 \text{ N/mm}^2$						BLOCKWORK, $f_{ck} = 7 \text{ N/mm}^2$					
	CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)		CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)		CHARACTERISTIC LOAD (kN)		DESIGN LOAD (kN)		RECOMMENDED LOAD (kN)	
	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})	TENSION (N_{Rk})	SHEAR (V_{Rk})	TENSION (N_{Rd})	SHEAR (V_{Rd})	TENSION (N_{Rec})	SHEAR (V_{Rec})
M5	2.4	3.4	1.1	1.9	0.9	1.6	1.9	3.4	0.9	1.9	0.8	1.6	1.5	2.3	0.7	1.3	0.6	1.1
M6	3.7	5.2	1.7	2.9	1.4	2.4	3.2	5.2	1.5	2.9	1.3	2.4	2.4	2.5	1.1	1.4	0.9	1.2
M8	5.0	8.6	2.3	4.8	1.9	4.0	4.5	8.6	2.1	4.8	1.8	4.0	3.5	2.7	1.6	1.5	1.3	1.3
M10	6.0	10.3	2.8	5.7	2.3	4.8	5.6	10.3	2.6	5.7	2.2	4.8	4.5	3.1	2.1	1.7	1.8	1.4
M12	7.3	13.1	3.4	7.3	2.8	6.1	6.9	13.1	3.2	7.3	2.7	6.1	5.8	3.4	2.7	1.9	2.3	1.6

For further explanations on calculations please see pages 10 and 11
When calculating loads in brickwork and blockwork apply the published edge distance and spacing for concrete and assume these figures to be the absolute minimums. Concrete reduction factors must NOT be applied.

Reduction Factors - Edge and Spacing Distances for Rawlok® Sleeve Anchor Bolt Projecting.

The full characteristic edge and spacing distances shown in the table above are the minimum allowable for the quoted DESIGN RESISTANCE or RECOMMENDED LOAD, depending on your design method.

Where these dimensions are not achievable, the appropriate reduction factor/s from the tables below must be applied to the DESIGN RESISTANCE or RECOMMENDED LOAD.
Choose the required bolt diameter across the top of the appropriate table and read down the left hand column until actual edge or spacing distance is found.

Read off the reduction factor where the two lines intersect (interpolate as required).
Multiply this factor by the DESIGN RESISTANCE or RECOMMENDED LOAD quoted in the table.
On the occasion that multiple close edge and/or spacing distances occur, the appropriate reduction factors must be applied.

Edge Distance (Concrete Only)

EDGE (mm)	TENSILE: EDGE REDUCTION FACTORS					EDGE (mm)	SHEAR: EDGE REDUCTION FACTORS				
	M5	M6	M8	M10	M12		M5	M6	M8	M10	M12
40	0.75					40	0.58				
50	0.87	0.79				50	0.79	0.53			
60	1.00	0.89	0.81			60	1.00	0.69	0.50		
70		1.00	0.91	0.77		70		0.84	0.62	0.48	
80			1.00	0.85		80		1.00	0.75	0.58	
90				0.92	0.81	90			0.87	0.69	0.45
100				1.00	0.87	100			1.00	0.79	0.53
120						120				1.00	0.69
140						140					0.84
160						160					1.00

Spacing (Concrete Only)

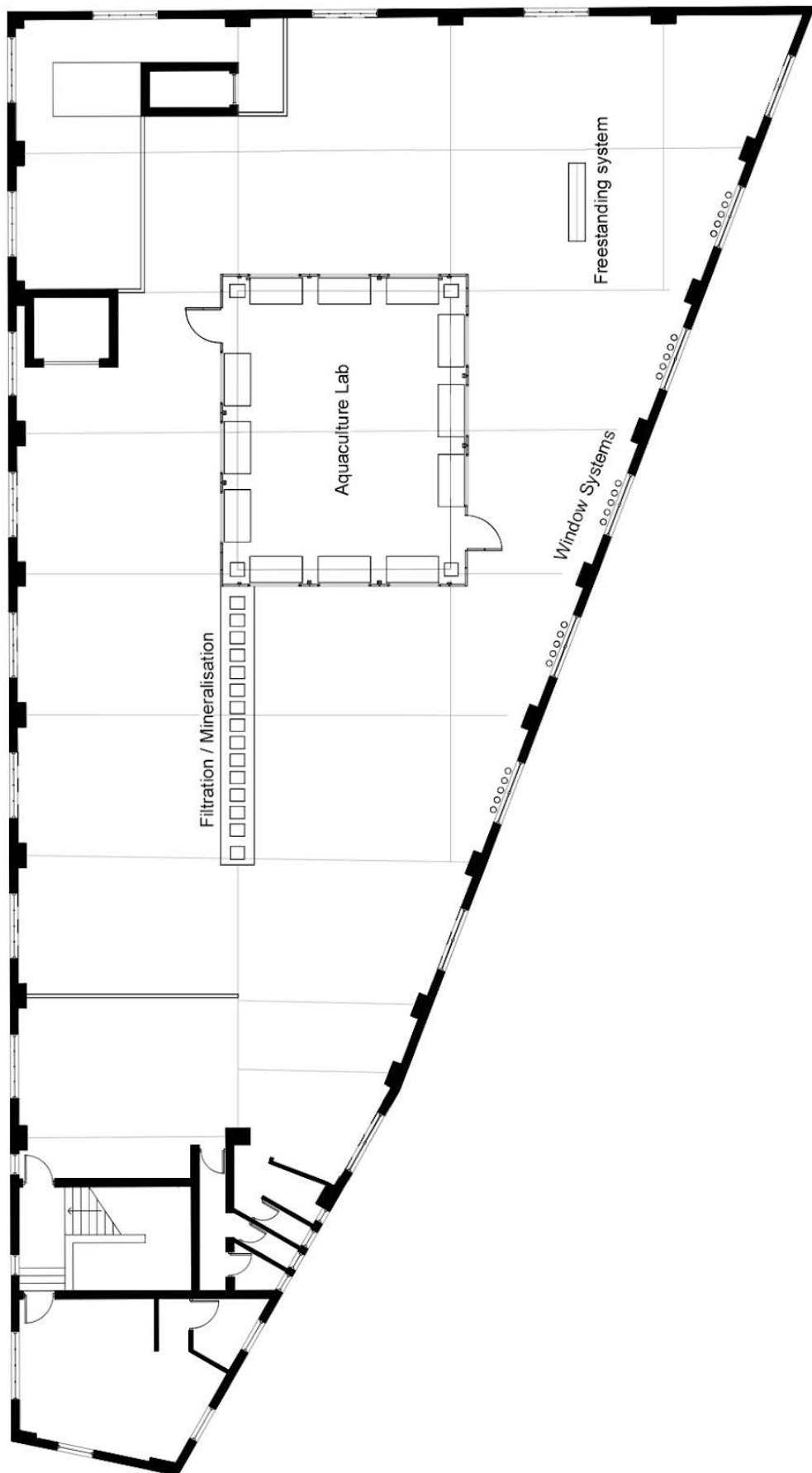
SPACING (mm)	TENSILE & SHEAR REDUCTION FACTORS				
	M5	M6	M8	M10	M12
40	0.80				
50	0.90	0.77			
60	1.00	0.85	0.76		
70		0.92	0.82	0.75	
80		1.00	0.88	0.80	
90			0.94	0.85	0.74
100			1.00	0.90	0.77
120				1.00	0.85
140					0.92
160					1.00

7.0 Sketches / Extract References

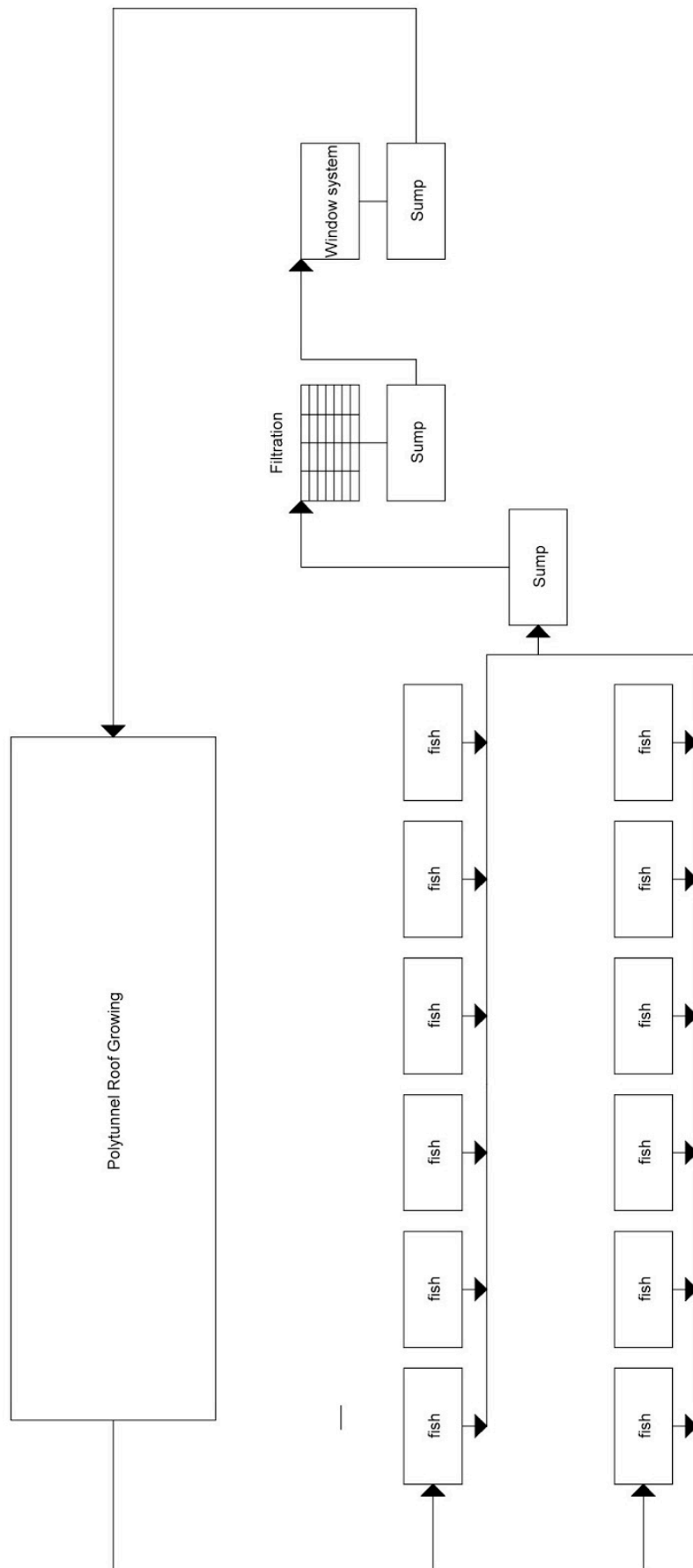
Roof Level Beam Reference	SK01
Beam reactions with proposed loadings	SK02
Second Floor Propose Layout Beam Reference	SK03
Lintel Reference	SK04
B10 Façade – Structural Opening	SK05
Historial Structural Steelwork Handbook –	
Imposed loads from BS449 1948	EX01
Rawlok Bolt Production Information	EX02

APPENDIX

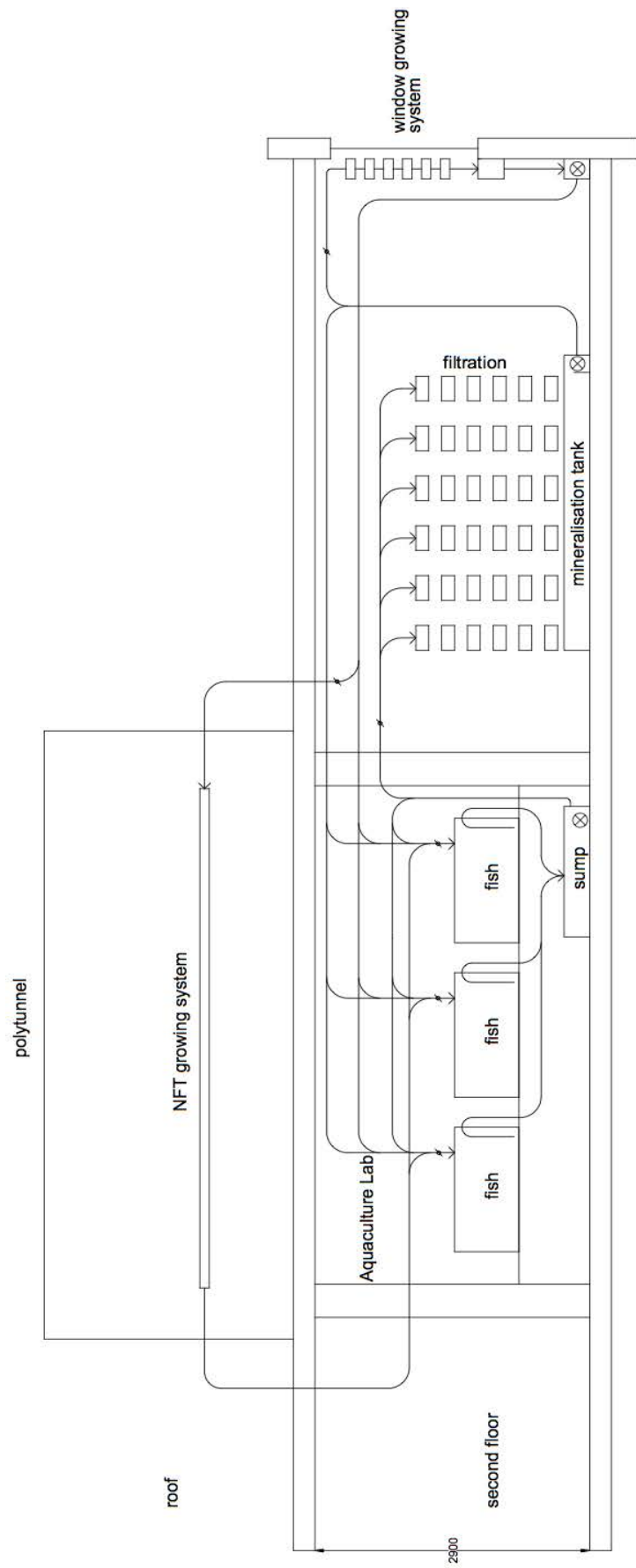
H



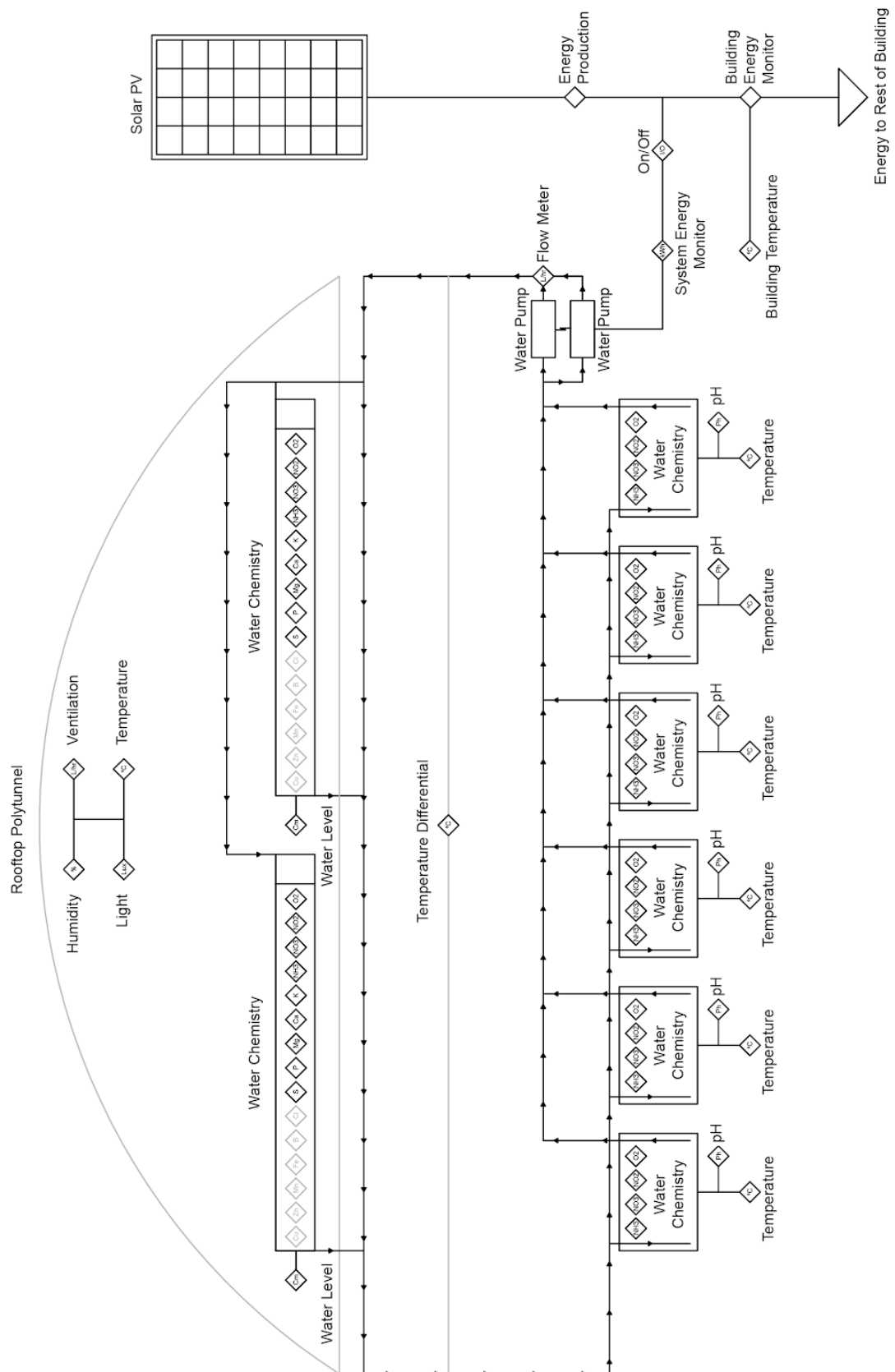
Amended aquaponic design with filtration unit and window growing systems



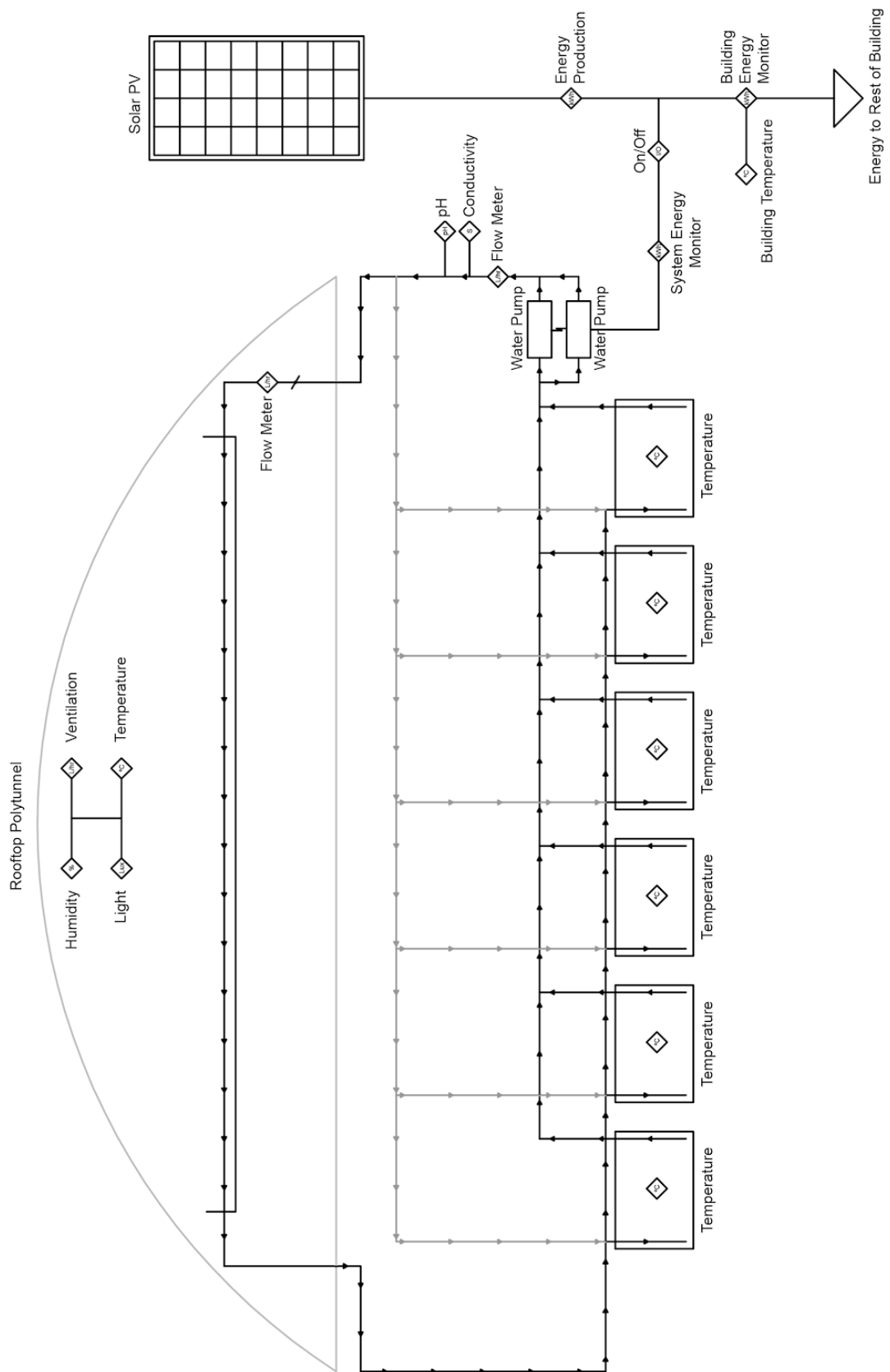
Intermediate schematic design for the elevated aquaponic system



Operational schematic of the elevated aquaponic system



Original monitoring schematic for the elevated aquaponic system



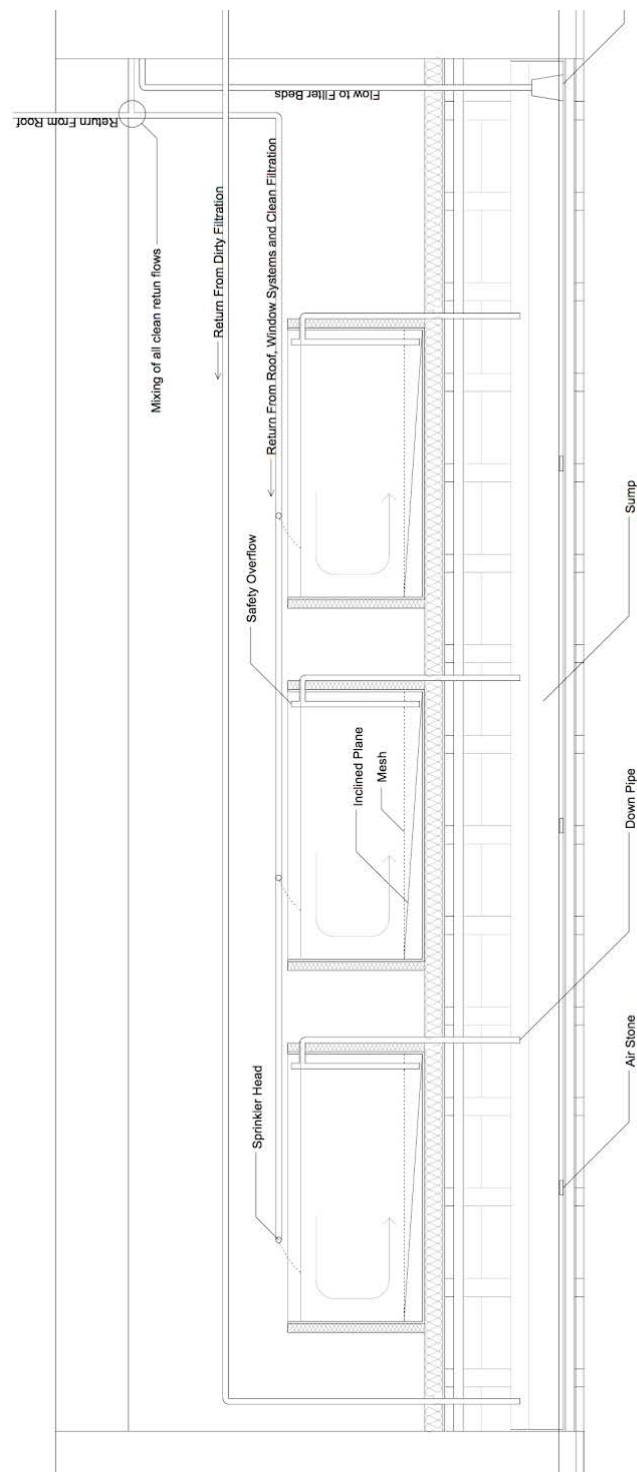
Revised monitoring schematic for the elevated aquaponic system

APPENDIX

I

APPENDIX I

Elevated aquaponic system - Aquaculture lab



Detailed design of the aquaculture lab



Square frames to form timber box sections



Three side of the aquaculture lab comprised from timber box sections



Plywood and rubber sump built into the box section of the aquaculture lab



The four sides of the aquaculture lab built from timber box sections with insulated pads awaiting positioning of fish tanks



Glass fish tanks positioned on top of insulated pads



Walls of the aquaculture lab supported by the timber box sections



Plasterboard added to exterior of aquaculture lab



Completion of plasterboard exterior skin of aquaculture lab



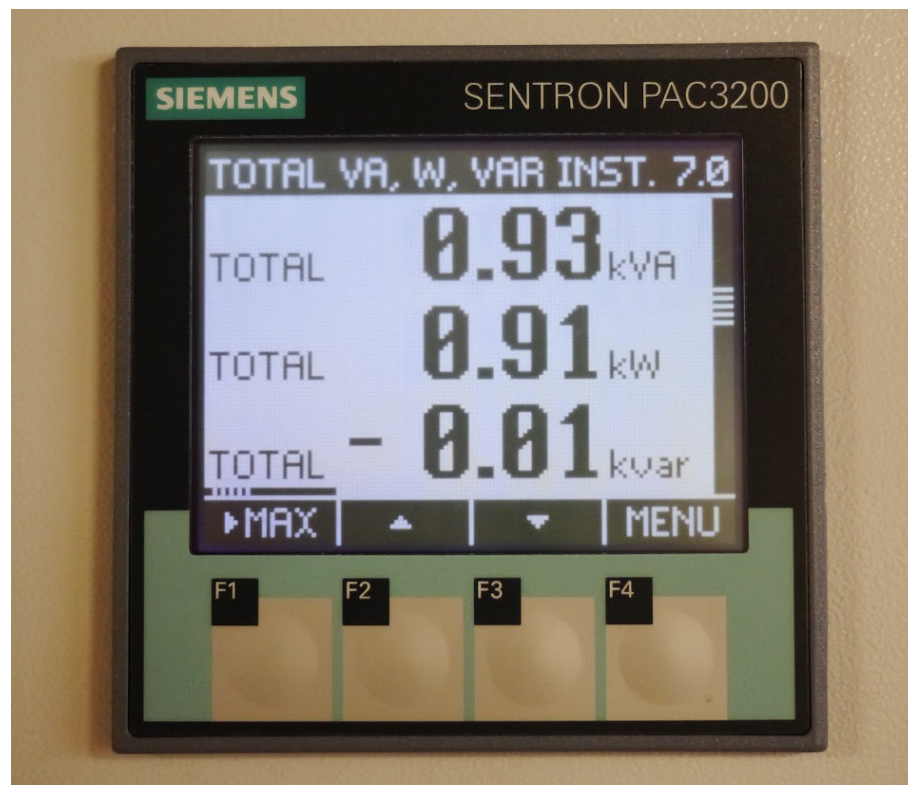
Completed aquaculture lab



Tilapia within the aquaculture lab



Touch screen interface of the elevated aquaponic system as part of the aquaculture lab



Energy read out for the elevated aquaponic system from the control board

APPENDIX

J

APPENDIX J

Elevated aquaponic system - Filtration unit



Detailed design of the filtration unit



Initial exterior framework of the filtration unit



Completed framework of the filtration unit



Painting the filtration unit



Drainage pipe of the syphon design being fitted to the washing up bowls



Drainage pipes fitted to all 98 washing up bowls



Testing the syphon design to ensure the syphon engages and stops are required



Filtration basket fitted around each syphon to enable maintenance



Outer shell of the syphons



Fitting the hangers from which the washing up bowls will be suspended



Washing up bowls installed within filtration unit with plywood and rubber sump in the bottom



Washing up bowl filled with hydroton



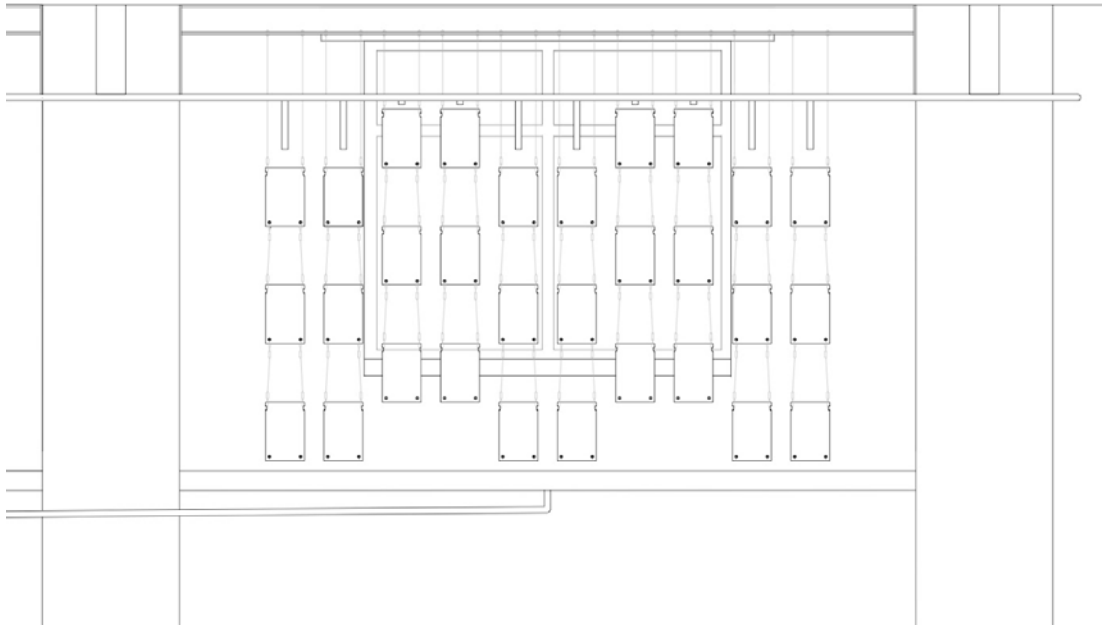
Completed filtration unit

APPENDIX

K

APPENDIX K

Elevated aquaponic system - Window system



Detailed design of a single window system



Workmen on site ready to fit steel lintels to support both the roof and window systems



Workmen fitting steel lintels to brickwork piers



Production of silicone bags



Suspension of the first window system as viewed from the filtration unit



Silicone bag filled with hydroton and pipe from bag above to minimise splashing



Silicone bags suspended from steel lintel



Initial planting of the window system



First tomatoes from the window system



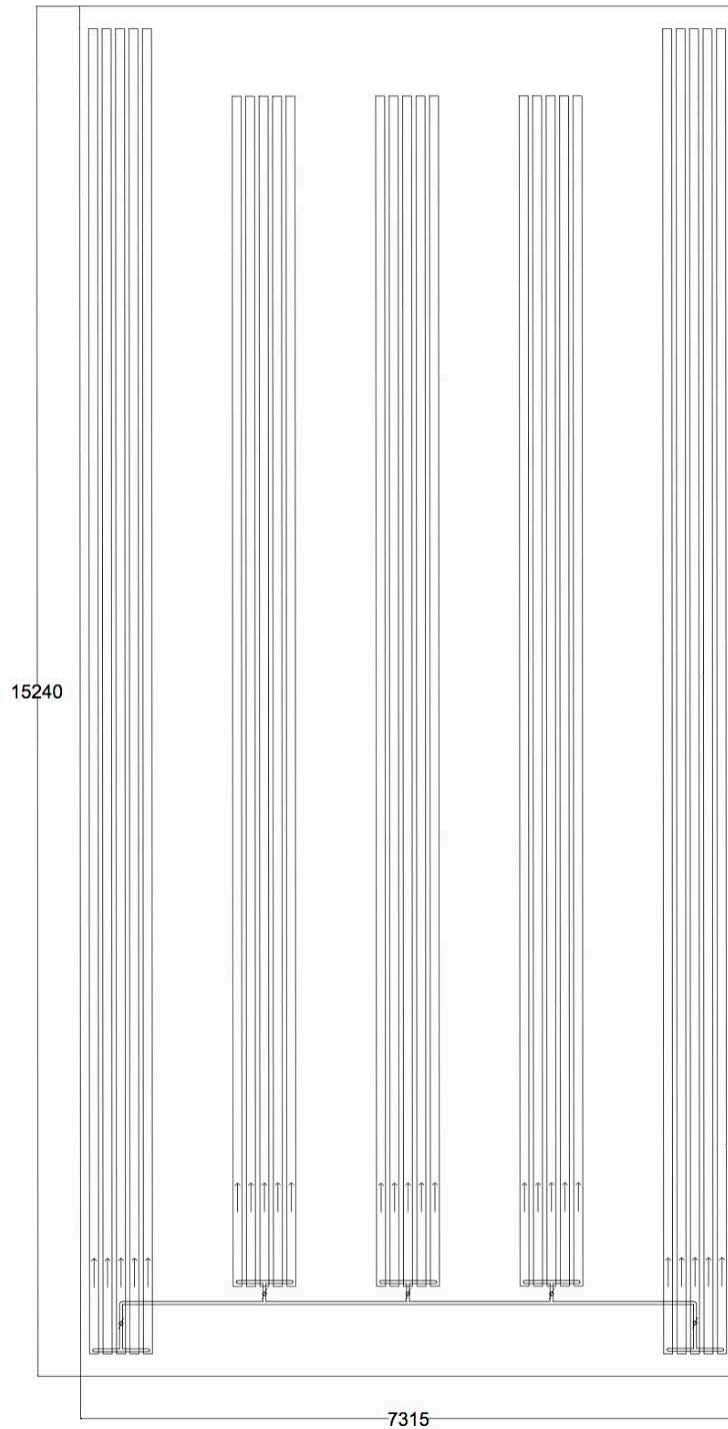
View along all five window systems

APPENDIX

L

APPENDIX L

Elevated aquaponic system - NFT system



Detail design for the rooftop NFT system



Drilling of the larger NFT holes in the electrical conduit lid



Drilling of the smaller NFT holes in the electrical conduit lid



The small and large holes with appropriately sized crop basket installed



Rooftop polytunnel illuminated at night during construction



NFT system after initial planting



Lettuce after a few weeks of growth



Visitors exploring the NFT system during the festival



Full length of the rooftop NFT system



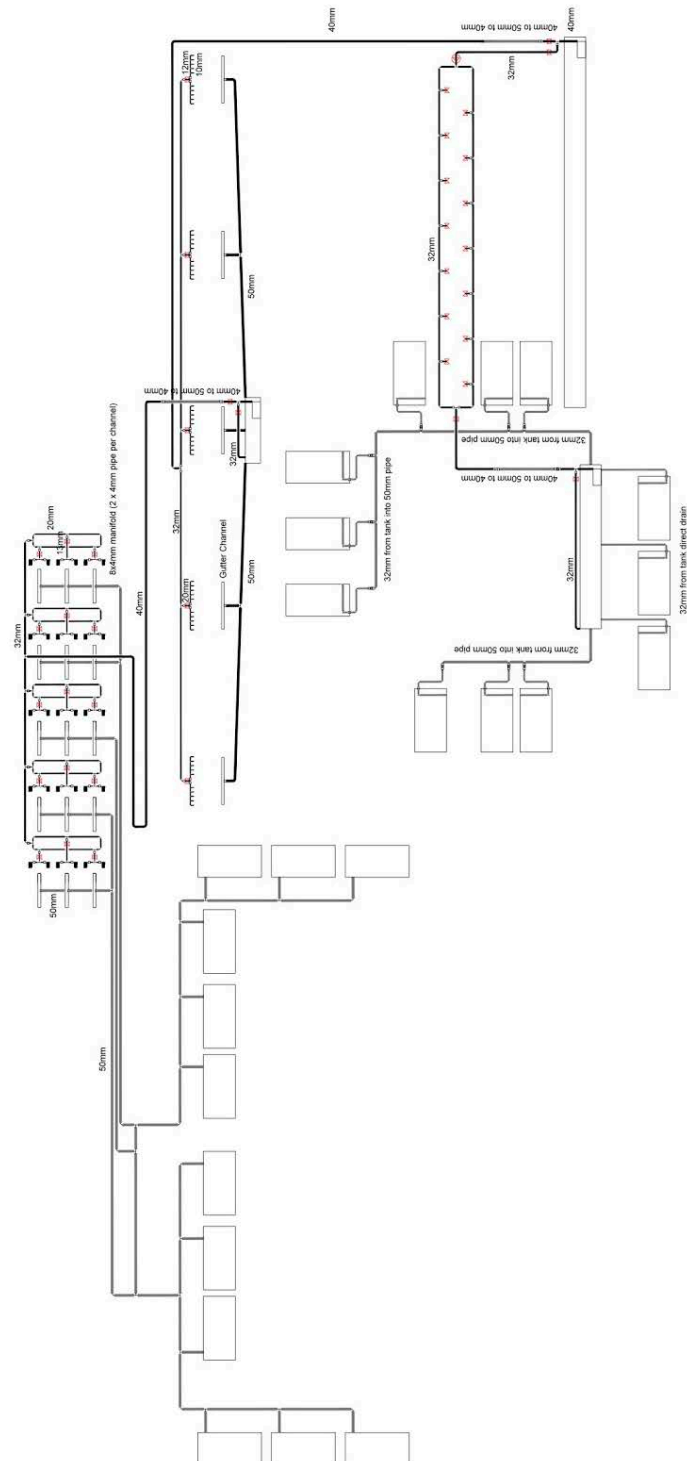
Aerial view taken from the adjacent residential tower showing Irwell House on the right and the community garden to the left

APPENDIX

M

APPENDIX M

Elevated aquaponic system - Pipes and plumbing



Detail design of the pipes and plumbing required to move water around the system



Outflow from each fish tank



Main drainage from the fish tanks



'T' splitter to transport water around the top of the filtration unit



Valve after the filtration sump to help better balance the water travelling to the window system



Flow meter installed above the filtration unit



'T' splitter to deliver an equal proportion of water to the different window systems



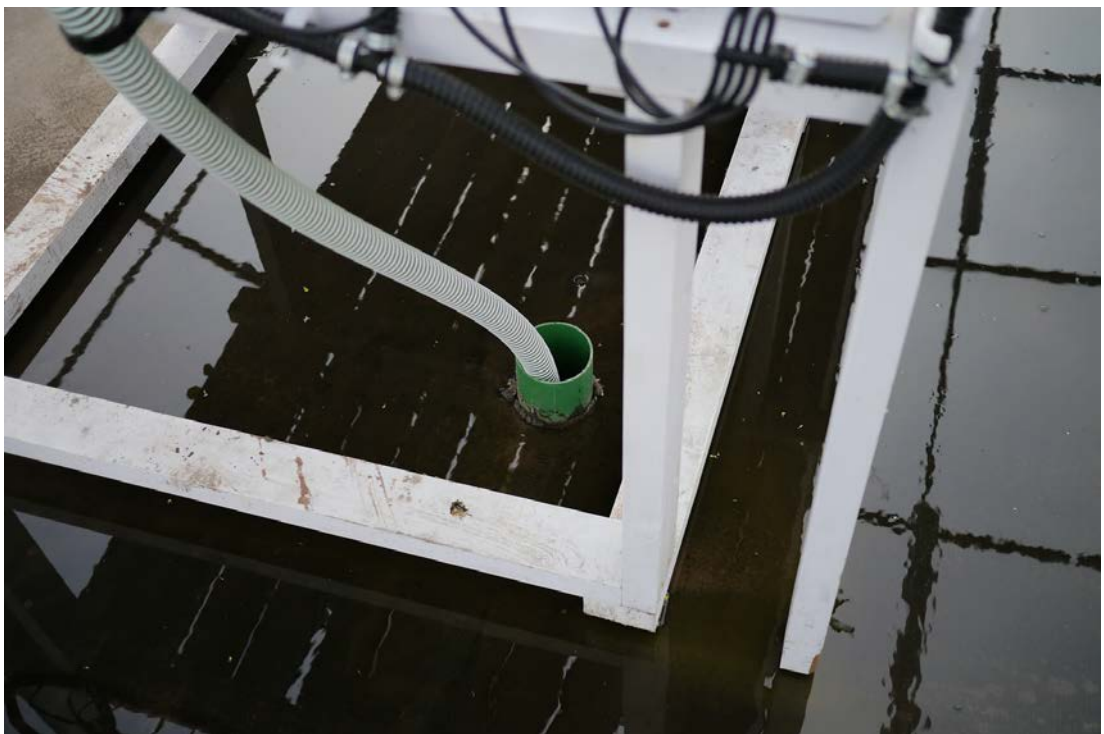
'T' splitter and subsequent feeds above each window system to deliver sufficient water to the grow bags



Window system drainage to transport water to the window sump



Water from the window system sump being pumped up to the rooftop NFT system



Water feed from the second floor to the roof



Irrigation splitter to ensure each NFT channel receives the same volume of water



Two outlets were provided for each NFT channel to ensure sufficient water movement through the system



Plant baskets utilised as filters at the end of each bank of NFT channels to restrict the movement of plant debris



Drainage from the rooftop NFT system running along the framework



Drainage from the roof back down to the floor beneath



Return water from the roof to provide each fish tank with fresh clean water

APPENDIX

N

APPENDIX N

Elevated aquaponic system - Final costs

AQUACULTURE LAB	COST
Timber (whole project)	£1,479.00
Additional timber cladding rails	£60.40
Tanks	£3,570.00
Plywood (whole project)	£327.46
Rubber (whole project)	£580.00
Pumps (whole project)	£1,675.00
Pipework, valves and fittings (whole project)	£2,600.00
UV Steriliser (whole project)	£299.89
Fish	£1,320.00
Water Heaters (x12)	£180.00
Insulation	£322.83
Plasterboard	£500.00
Aquaponics Float	£200.00
TOTAL	£13,114.58
FILTRATION UNIT	
Timber	Included in above
Threaded Bar	£192.00
Hex Nuts	£4.60
Washers	£31.90
Head Rail	£166.66
Sump	Included in above
Pump	Included in above
Media/Gravel	£300.00
LED lights	£105.95
Airstones	£90.66
Air Pump	£134.97
Airline	£20.95
Worms	£1,050.00

50mm Pipe	£37.50
20mm pipe	£11.44
50mm Stop Ends	£132.00
Plastic Mesh	£16.67
Lighting (x15)	£88.29
Bowls (x100)	£343.55
Outer Skin (Corrugated UPVC)	£300.00
TOTAL	£3,027.14
NFT SYSTEM	
Steel	£2,400.00
Polytunnel	£2,426.25
NFT Gutter	£1,059.75
NFT Lid	£1,260.00
Plants	£580.00
Electrics (whole project)	£1,400.00
Rockwool	£285.00
Net Pots	£556.95
TOTAL	£9,967.95
WINDOW SYSTEM	£0.00
Wire, clamps etc.	£127.80
Snap Hook Wires	£51.17
Caddy Clips	£183.00
Split Bolts	£17.52
Silicon Sealant	£494.50
Silicone sheet	Included in above
Media/Gravel	Included in above
Pipework	Included in above
Valves & Fittings etc.	Included in above
Sump (Inc. drains etc.)	Included in above
Pump	Included in above
TOTAL	£873.99
MISCELLANEOUS	
Petty Cash Float	£500.00

Tools	£463.00
Screws	£89.78
Screws 6x120	£50.75
Screws 4x40	£10.75
Gloves	£4.45
Hammer	£5.15
Masks	£2.49
Seeds	£141.04
Fish Feed	£18.85
TOTAL	£1,286.26
GRAND TOTAL	£28,269.92

APPENDIX

0

APPENDIX 0

Elevated aquaponic systems - Operations Manual

THE ELEVATED AQUAPONIC SYSTEM

AQUAPONICS OPERATIONS AND MAINTENANCE MANUAL

PRODUCED BY: QUEEN'S UNIVERSITY BELFAST

PRODUCED FOR: THE BIOSPHERIC FOUNDATION

DATE PRODUCED: 04/11/2013

NAMED MEMBER OF STAFF:.....

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0.0 Executive summary

The Biospheric Project is an experimental building-based aquaponic system, developed not only as an exhibit for Manchester International Festival 2103, but also as a research facility and food producing facility beyond the Festival. The experimental nature of the project means that although the system has elements that are automated, the system is not automatic: it needs continuous attention in order to run efficiently and safely.

Particular issues to note are:

Health and safety of operators and building users –

The system contains elements that can be considered hazardous – such as pump impellers – electrical installations – working at height- contact with living organisms.

Legionella risk –

All water based systems harbour possibly dangerous bacteria. In the case of the Biospheric Project, the risk from legionella is classified as low – but it is still essential to monitor and maintain the system correctly to protect against build up.

Living things –

The Project although technological is still a farm, and needs treating as such. The fish and animals need constant care and attention.

Energy use –

The system also uses energy, and was designed to work with a photovoltaic array. Without the array, there will be considerable running costs incurred in keeping the system functioning.

Water usage –

The system has a requirement for a continued supply of fresh water – mainly due to the transpiration of plants, evaporation from parts of the system, and leaks. In warm weather in particular water usage can be dramatically increased.

0.1 Introduction

The aquaponic system situated within Irwell House is highly experimental and highly fragile. It has been developed as an operational farm and as with all farms, needs constant care and attention. A duty of care toward the aquaponic system will not only promote the safe running of the system and minimise incidents but will also ensure the well being of the fish and crops within the system as well as the people around it.

It is suggested that the farm be looked after daily by a dedicated member of staff or team which can easily conduct all daily, weekly, monthly, quarterly and yearly tasks stated within this document with ease, as well as caring for the plants and living things within the system, and making time for harvests.

It should be noted that an ecosystem has been created within the aquaponic system and cannot be simply switched off. The system is full of life and needs to be treated with respect. If for any reason there is a break in operation it should be the absolute priority to get the system up and running with immediate effect to protect the life within from distress or death.

The system wants to promote the welfare of living things as one of its key aims equal to that of growing food within an urban context.

0.2 The Basic Principles of an Aquaponic System

An aquaponic system in its simplest form wants to take abundant ammonia from fish and convert it through biological filtration into nitrogen for plants.

Fish produce vast quantities of ammonia and if this is not dealt with it can reach toxic levels and lead to fish death. By using bacteria species that naturally occur in ammonia rich water this toxic chemical compound (NH_4) can be converted into Nitrite (NO_2) by Nitrosomonas bacteria. Nitrite is still toxic to fish and of little use to plants. In the presence of Nitrite the population of Nitrobacter bacteria increases, and is able to convert Nitrite into Nitrate (NO_3). Nitrate is a poly-ionic ion of Nitrogen, which is easily diffused across the epithelium of root structures to nourish the plant.

Nitrogen is an essential macronutrient needed by all plants to thrive. It is an important component of many structural, genetic and metabolic compounds in plant cells. It is also one of the basic components of chlorophyll, the compound by which plants use sunlight energy to produce sugars during the process of photosynthesis.

Aquaponic systems take a waste chemical from fish and convert it into an essential nutrient for plants. In principle, there is no trace of the original ammonia as it has been converted into nitrate and no trace of the nitrate as the plant has absorbed it from the water. The water is clean ensuring the well being of the fish and the plants are fed ensuring the crops well being.

The bacteria utilised within the system are aerobic which denotes they require oxygen to survive and thrive. If the oxygenation of the water is poor then the populations of bacteria will diminish and be replaced by anaerobic bacteria. Anaerobic bacteria function in the exact opposite way to aerobic bacteria and will take available nitrogen and convert it back into ammonia leading to higher levels of ammonia within the system than expected, and to fish deaths. The regular cleaning of the system will greatly reduce the possibility of dead spots and dirt on which anaerobic bacteria can thrive.

ATTENTION!

The maintenance of the system is not only key to the success of the system but a key concern to the health and well being of the people who occupy the space around it. The maintenance schedule should be followed to the last detail and prioritised at all times. The failure to do so could impact on the health of the fish, health of the crops, health of the ecosystem encapsulated within the system or the health of the people working directly on it or around it. Please refer to the cleaning schedule

at the beginning of the document as well as the cleaning schedule forms at the end of the document contained within appendix A

PART A: OPERATIONS

A.1.0 Operations Manual

The purpose of this manual is to ensure the sufficient monitoring and maintenance of the aquaponic system. It is a complex system and proper maintenance will be required daily, weekly, monthly, quarterly and annually. The named member of staff should in all instances, carry out these tasks. This person should have a working knowledge of plumbing, water chemistry, and basic construction as well as a very good working knowledge of the wellbeing of fish, plants and worms. The sections below outline the jobs that need to be carried out within these timeframes. The first section will simply list these key tasks with further details of how to perform them in the next section.

ATTENTION!

To the rear of this document there is succession of forms, which combine to assemble the maintenance schedule. The maintenance schedule should be filled out daily, weekly, monthly, quarterly and annually in accordance with the tasks set out below. All documentation regarding maintenance should be kept at the rear of this manual as a record of work conducted. It is of paramount importance that these forms get filled out and signed off by the named member of staff. The named member of staff should conduct each section of the maintenance schedule personally to ensure quality.

FAILURE TO DO THE ABOVE WILL LEAD TO THE IMMEDIATE SHUTDOWN AND DECOMMISSIONING OF THE SYSTEM. ONLY WHEN IT IS KNOWN THAT A GOOD STANDARD OF MAINTENANCE AND CARE CAN BE ACHIEVED WILL THE SYSTEM BE ALLOWED TO RETURN TO AN OPERATIONAL LEVEL.

ATTENTION!

Before ANY work is conducted on the pumps the system MUST be switched off on the Siemens panel by the isolator switch, the plug socket in which the pump is located MUST be switched off and pumps MUST be unplugged. Failure to do this could lead to significant injury. This is non-negotiable and must be adhered to regardless of the views of the person or persons undertaking the work.

A.1.1 Summary of operation tasks – Aquaponic System

A.1.1.0 Daily tasks

These tasks should be completed on a daily basis and recorded, with any additional information detailed. A sample record sheet can be found in Appendix A01.

ATTENTION!

The named member of staff should complete all the tasks listed below and should not be performed by others. If for any reason the named member of staff cannot perform these tasks, a pre-appointed and fully trained person should conduct the full list of daily tasks in his or her place.

A.1.1.0.0 Morning tasks: The following tasks are required at the start of each day. (Inc. weekends)

Full walk around of aquaponic system, inspecting ALL joints (inc. roof joints) for leaks and any other issues whilst system is ON.

Check all fish tanks are receiving water from the roof.

Check all air stones are operational in each fish tank and ionisation tank.

Check all fish tank outflow pipes are connected and vertical.

Check for splashing in window bags and remedy if necessary.

Turn system OFF at isolator switch.

Turn all three pumps off at their respective plugs and unplug them

Uncouple all three pumps from pipe work and remove from sump after draining pump of access water.

Inspect all pumps for blockages.

Remove any blockages.

Deep clean inside pumps.

Remove and clean filters connected to all pump inlets.

Full inspection and removal of debris from sumps including clay media, dead fish, plants, leaves etc.

Reconnect pipe work to pumps.

Test Pumps for spraying from connections, afterwards leaving the system OFF to continue inspections.

Uncouple all three UV filters.

Remove all three UV filters from wall.

Disassemble all three UV filters.

Full clean of the inside of all three UV filters.

Reassemble all three UV filters, fix back to wall and reconnect pipe work.

Pressure test all UV filters units, afterwards leaving the system OFF.

Inspect all roof manifolds for blockages.

Clean out all lengths of 4mm black hose on roof.

Check NFT channels are free from obstruction.

Check NFT debris baskets are clear of obstruction.

Check all outlet bungs on window outlets at the top of the bags are still in place.

Clean return gutters on window system.

Ensure window debris collectors are clear.

Turn system ON.

Check bilge pump in window sump is operating correctly.

Check all pH baths are flowing.

Ensure tank heaters are operational where applicable.

Clean out the two filter pumps located in fish tanks.

Remove airlocks at every outlet valve.
Inspect all valves for blockages.
Remove valve blockages if necessary.
Inspect filtration pods for blockages.
Remove filtration blockages if necessary.
Fill the System (if required)
Final full walk around to ensure all work is completed to high standard.

A.1.1.0.1 Afternoon tasks: The following tasks are required throughout each day. (Inc. weekends)

- *Feed the fish their daily amount of food specified on feeding schedule.*
- *Clean fish tank glass.*
- *Check pH Level and record*
- *Full walk around of aquaponic system, inspecting ALL joints (inc. roof joints) for leaks and any other issues whilst system is ON.*
- *Check for splashing in window bags and remedy if necessary.*
- *Ensure all 4mm hose outlets on roof are flowing freely and attend to the ones that aren't.*
- *Remove airlocks at every outlet valve.*

A.1.1.0.2 End of day Tasks: The following tasks are required at the end of each day. (Inc. weekends)

- *Remove all uneaten food from fish tanks.*
- *Remove airlocks at every outlet valve.*
- *Clean out all lengths of 4mm black hose on roof.*
- *Check bilge pump in window sump is operating correctly.*
- *Check all air stones are operational in each fish tank and ionisation tank.*
- *Check all fish tanks are receiving water from the roof.*
- *Final full walk around to ensure all work is completed to high standard and safe to be left overnight.*

A.1.1.1 Weekly tasks

These tasks should be completed on a weekly basis and recorded, with any additional information detailed. A sample record sheet can be found in Appendix A02.

Weekly tasks: The following tasks are to be completed at the beginning of every week.

- *Chemical water tests.*
- *Inspect sumps for wear or damage.*
- *Clean sumps, remove water, dry, repair if required and refill*
- *Clean window bags inside and out*
- *Repair any broken joints on window bags with silicone (Food Grade only)*
- *Clean NFT channels*
- *Clean every side of fish tanks*

A.1.1.2 Monthly tasks

These tasks should be completed on a monthly basis and recorded, with any additional information detailed. A sample record sheet can be found in Appendix A03.

Once a month tasks: The following tasks are to be completed at the start of each month.

- *Change first set of 10mm clear hose atop of window system for second set.*
- *Place outlet bungs into the new sections of 10mm clear hose.*
- *Clean and dry first set of 10mm clear hose ready for next months change.*
- *Change first set of 4mm black hose and manifolds on roof for second set.*
- *Clean and dry first set of 4mm black hose and manifolds ready for next months change.*
- *Disassemble all push fit components, deep clean and reassemble.*
- *ALL joints to be inspected in detail and fixed/tightened where required.*

A.1.1.3 Quarterly tasks

These tasks should be completed on a quarterly basis and recorded, with any additional information detailed. A sample record sheet can be found in Appendix A04.

Deep clean of ALL piping.

Deep clean of ALL filtration pods.

A.1.1.4 Annual tasks

These tasks should be completed on an annual basis and recorded, with any additional information detailed. A sample record sheet can be found in Appendix A05.

- *Full shut down, deep clean and restart (please refer to '4.0 Deep Clean')*

A.1.1.5 Additional tasks

These tasks are without time frame but should be completed on an as and when basis, with any additional information detailed. A sample record sheet can be found in Appendix A06.

- *Clean fish net after use.*
- *Fish tank deep clean.*
- *NFT Channel deep clean.*
- *Washing of media balls.*

A.1.2 Full description of tasks – Aquaponic System

ATTENTION!

The named member of staff should complete all the tasks listed below and should not be performed by others unless accompanied by the named member of staff. In ALL instances, Please refer to section '2.0 Hardware' for further information on each noted point below

A.1.2.0 Daily Tasks

A.1.2.0.0 Morning Tasks

Morning tasks: The following tasks are required at the start of each day. (Inc. weekends)

- ***Full walk around of aquaponic system, inspecting ALL joints (inc. roof joints) for leaks and any other issues whilst system is ON.***
- At the beginning of every day the operations manager is to inspect every single joint and length of pipe within the system for leaks, drips, signs of wear and any other issues. This detailed survey will not only identify and flag up issues on a daily basis but will also draw attention to reoccurring problems. The issues encountered and actions taken will need to be recorded on the 'Daily Inspection' section of the daily maintenance form at the rear of this document and signed and dated by the named member of staff. (See appendix A01)

This walk around should also include the inspection of the living things within the system. That includes the inspection of the fish, the inspection of the worms and inspection of the crops both in the window system on the second floor and the crops within the NFT system located on the roof. The named member of staff should have the experience to address all problems relating to the fish, worms and plants within the system. If the named member of staff feels they lack in any of these areas it is recommended that they attend training to ensure their knowledge is of a good enough standard to run the system.

- ***Check all fish tanks are receiving water from the roof.***
- The return pipe work from the roof has been designed in such a way that every tank receives a fair share of water. Although this is the case, slight movements in pipe work during feeding/maintenance can affect this so should be checked daily.
- ***Check all air stones are operational in each fish tank and ionisation tank***
- The named member of staff should sign off that each air stone is operational in each tank and also within the ionisation tank. If the air stone is not functioning correctly it could indicate that the air stone has cracked or the airline is bent, folded or blocked.
- ***Check all fish tank outflow pipes are connected and vertical.***
- The vertical white pipes within the fish tanks can become dislodged due to fish swimming into them. They should be connected and placed vertically to maximise **their**

efficiency at removing solid waste from the tanks. This check ensures that water quality remains high.

- ***Check for splashing in window bags and remedy if necessary.***
- Sometimes the outlet pipes or down pipes can move as part of the window system, or the media within the bags can move, creating splashing. Rectifying these splashes quickly will minimise water loss and maintenance (ie. mopping)
- ***Turn system OFF at isolator switch.***
- To complete the following tasks, please ensure the system is switched OFF at the isolator switch and a notice placed on the Siemens panel, ensuring all members of staff are aware that inspections are taking place. All members of staff need to be aware that the system is off for maintenance so there is no risk of them turning it back on.
- ***Turn all three pumps off at their respective plugs and unplug them.***

ATTENTION!

Before ANY work is conducted on the pumps the system MUST be switched off on the Siemens panel by the isolator switch, the plug socket in which the pump is located MUST be switch off and pumps MUST be unplugged. Failure to do this could lead to significant injury. This is non-negotiable and must be adhered to regardless of the views of the person or persons undertaking the work. Make sure the water is tipped out and allowed to drain from the pump before they are removed from the sump. This will reduce the amount of water that is lost from the system as also reduce maintenance.

- ***Uncouple all three pumps from pipe work and remove from sump after draining pump of access water.***
- Each pump is connected to a pipe. To allow easy inspection of the pumps, these pipes should be removed. The pumps should be held above the water line and tipped out and allowed for a short time to drain. This will ensure minimal water loss and cleaning.
- ***Inspect all pumps for blockages.***
- Although measures have been taken to prevent the blocking of the pumps, they are all still at risk of blockages. ALL three pumps should be checked daily to ensure the safe running of the system and to minimise the prospect of flooding.
- ***Remove blockages within pumps.***
- Ensuring that the pump is switched off and the plug unplugged from its socket, remove any and all blockages from the pump. The items removed should be thrown away to ensure the issue does not persist.
- ***Deep clean inside pumps.***
- After all blockages have been removed the internal chamber of the pump should be scrubbed to prevent dirt build up. Although the internal chamber is at high pressure,

dirt can still accumulate. The chamber should be scrubbed and rinsed out in fresh running water to remove the dirt from the system.

- ***Remove and clean filters connected to all pump inlets.***
 - The filters connected to each pump are the primary barrier against pump blockages and as a result should be cleaned daily. If the filters become blocked they will greatly restrict water flow into and out of the pump. This will lead to flood risks so should be kept clear at all times. The filters should be removed from the pumps and cleaned in fresh running water and replaced when clean.
- ***Full inspection and removal of debris from sumps including clay media, dead fish, plants, leaves etc.***
 - Each sump will collect debris throughout the day whether it be uneaten fish food, clay media balls, plant leaves etc. To avoid pump blockages the sumps should be checked for debris at the beginning of the day. It is advisable to do this whilst the pumps are removed to allow full and unrestricted access to the sump. All items removed from the sumps should be thrown away. This daily task will reduce the likelihood of flooding by removing the prospect of the filters blocking or the pumps blocking.
- ***Reconnect pipe work to pumps.***
 - Each pump when fully unblocked and cleaned, should be re-connected back to the system.
- ***Test Pumps for spraying from connections, afterwards leaving the system OFF to continue inspections.***
 - To ensure each pumps reconnection is watertight and able to withstand the high pressures of the pump, the pumps should be periodically turned on the check for leaks. Any leak, no matter how small, represents a weak spot and should be dealt with immediately. Only when all connections are successfully tested should the next tasks be completed
- ***Uncouple all three UV filters.***
 - The importance of having clean UV filters cannot be stressed enough due the impact they have on both the system health and also the health of the person working on and around the system. The first step to conducting this work is to remove the pipe work from the unit. It should be noted that the units would be full of water at this point so the top pipe should be removed first. In the instance of the horizontal UV filter take one pipe off first to allow some water to drain out. Measures should be taken to collect the vast amount of water into a large container. It would be beneficial to be able to reintroduce this drained water into a sump to reduce water loss when the system is reactivated.
- ***Remove all three UV filters from wall.***

- Once all the UV filters have been drained the UV filters should be removed from the wall and placed on a level and sturdy surface to allow cleaning and maintenance to be conducted easily.
- ***Disassemble all three UV filters.***
- The UV filter will disassemble into three main components; the plastic housing, glass encasement and UV light tube. All the components are fragile and should be treated with care. This will have been covered during training but for further information consult the Evolution Aqua Evo 30 UV Filter installation and operations manual.
- ***Full clean of the inside of all three UV filters.***
- Every corner of the inside of the larger plastic housing should be scrubbed clean and rinsed out under fresh running water to ensure no dirt is left behind. The exterior of the glass encasement should be cleaned, as this is the surface that allows the UV light to enter the water stream. It needs to be kept spotless. Time should be taken to conduct this work to a high standard due to the importance the work.

Please note that the internal surface of the glass encasement should be kept dry at all costs and that no water touch the UV light tube whatsoever. Take extra care in making sure no water comes into contact with any of the electrical components of the UV filter as this could lead to electric shock or the short circuiting of the UV filter.

- ***Reassemble all three UV filters, fix back to wall and reconnect pipe work.***
- Ensure all UV filters are reassembled correctly, fixed securely to the wall in the original positions and then reconnect pipe work securely.
- ***Pressure test all UV filters units, afterwards leaving the system OFF.***
- It is important that every joint, no matter its location or function, is always tested after work has been conducted on it. In the case of the UV filters this is also applicable. Each UV filter should be tested for leaks by temporarily turning each respective pump on and inspecting the unit for leaks. This will ensure that the work has been carried out correctly and will hold water securely for the next 24 hours, until the next inspection.
- ***Inspect all roof manifolds for blockages.***
- If the manifolds become blocked they will restrict the water flow to the NFT channels and therefore water into the fish tanks. It is import to keep these free of debris on a daily basis. Whilst the system is OFF detach the manifolds from the pipe work and remove any obstructions.
- ***Clean out all lengths of 4mm black hose on roof.***
- Solid waste can accumulate within the very small diameter of the 4mm hose. This makes them vulnerable to blockages and airlocks and should be unblocked where necessary to ensure the success of the system.
- ***Check NFT channels are free from obstruction.***

- To ensure water is allowed to move freely along the NFT channels and into the fish tanks, as well as reduce the risk of water loss through blockages, each NFT channel should be checked along its full length for debris build up or areas that may be likely to become blocked in the future. In both instances, actions should be taken to resolve the situation and debris removed.
- ***Check NFT debris baskets are clear of obstruction.***
- At the end of each NFT channel there is 2-inch net basket. These stop the migration of debris from the NFT channels into the fish tanks. These should be cleaned out daily to avoid blockages and prevent water loss.
- ***Check all outlet bungs on window outlets at the top of the bags are still in place.***
- The outlet pipe at the top of each column of window bags should be inspected daily to ensure the bung is still firmly wedged within it. If a bung works its way free the volume of water through those bags will increase leading towards splashing, overflow, or flooding. This step will reduce the risk of water loss from the system.
- ***Clean return gutters on window system.***
- Due to the shallow angle and easy access of the gutter returns on the window system they are subject to solid waste settlement and should be cleaned daily. The settled waste will provide the perfect breeding ground for anaerobic bacteria, which is to be avoided at all costs for the health of the system and the people working on it or around it.
- ***Ensure window debris collectors are clear.***
- It is important to check and clear the debris collectors located in the window return gutters to ensure they are functioning as designed. If debris is allowed to build up in this area it will lead to water build up within the window gutters as well as increasing the chance of flooding.
- ***Turn system ON.***
- With all the preceding jobs completed to a high standard, the following tasks should be conducted with the system switched ON.
- ***Check bilge pump in window sump is operating correctly.***
- The bilge pump located in the window sump is a flood prevention device and is intrinsic to the operation of the system. The float valve is connected to the larger pump located in the same sump. The larger pump will be removed daily and re-submerged after maintenance has been completed. It is important to check that the float valve is working, as it should, after this disturbance. The bilge pump should allow the window sump to fill but not overflow and then draining before switching off. Failure to spend time inspecting this will lead towards an increased risk of flooding. The operator should witness the sump fill and drain several times before they are satisfied that the float switch and bilge pump are working correctly.

- ***Check all pH baths are flowing.***
 - To ensure the pH data is accurate, water must be flowing through the pH baths in which the pH probes are located at all times. Checking this will ensure the date is correct. If no water is flowing, please repeat the air lock removal steps on the valve located at the pH bath in question.
 - ***Ensure tank heaters are operational where applicable.***
 - If tank heaters are used, these need to be checked daily to ensure they are operational and working as expected.
 - ***Clean out the two filter pumps located in fish tanks.***
 - The two filter pumps located within the murkiest tanks should be cleaned out daily to ensure they are working at full capacity. Due to the role they provide within the system they will quickly fill with solid waste. They should be rinsed with fresh running water and returned to the tanks afterwards.
 - ***Remove airlocks at every outlet valve.***
 - The potential of airlocks within the system is high so every outlet valve should be turned off and straight back on to allow trapped air to leave the system. This should be done several times to be sure that all the air has escaped. This includes the valves at the top of the filtration unit, window system and on the roof. It is very important this is completed daily to ensure the health and well being of system by allowing as much water to flow as possible.
- Please note this task does not include the valves associated directly with the pumps. Closing these will affect water flow through the system and may cause damage to the pumps. (See 'Pump Valves' for details).
- ***Inspect all outlet valves for blockages.***
 - For the success of the system to be maintained, everything that has been designed to receive water, should receive water. The blockage of any valve will impact on the health of the system. All outlet valves should be inspected for blockages. This includes expanded clay balls, uneaten food and solid waste.
 - ***Remove outlet valve blockages if necessary.***
 - A blockage can partially restrict water flow or fully restrict it. In both cases the system should be switched off, the valve in question removed and the blockage dislodged. The valves should then be reconnected and the system switched on to ensure the problem has been alleviated, and that the reconnection of the value is strong enough to restrict the water pressure and not drip.
 - ***Inspect filtration pods for blockages.***

- Water should at all times move freely through the filtration bank. If for any reason a filtration pod becomes blocked it will hinder the effectiveness of the filtration bank. A blockage would also lead towards a filtration pod overflowing, putting media balls and worms into the sump. Inspecting all the filtration pods will reduce the risk of overflow as well as splashing, which will reduce maintenance time.
- ***Remove filtration blockages if necessary.***
- If a filtration pod is blocked the system should be immediately switched off. The filtration pod, once drained can then be removed from the system and the blockage addressed. Once the problem has been resolved the filtration pod can be replaced and the system switched back on.
- ***Check all fish tanks are receiving water from the roof.***
- The return pipe work from the roof has been designed in such a way that every tank receives a fair share of water. Although this is the case, slight movements in pipe work during feeding/maintenance can affect this so should be checked daily.
- ***Fill the System (if required).***
- Due to evaporation, spillages, blockages and crop use, the water contained within the system will gradually drop. It is important that the system be filled daily to ensure there is enough water moving through the system to ensure the well being of the living things within it. It is advised to employ the use of a timer when filling. This will ensure enough is added to the system but not forgotten about leading to flooding.
- ***Final full walk around to ensure all work is completed to high standard.***
- To ensure all the work conducted is of a high standard a final walk around should be conducted checking all points for leaks or errors. Any errors will need to be addressed immediately. Only when this has been completed can the morning tasks be signed off.

A.1.2.0.1 Afternoon Tasks

Afternoon tasks: The following tasks are required throughout each day. (Inc. weekends)

- ***Feed the fish their daily amount of food specified on feeding schedule.***
- In accordance with the feeding schedule the fish should be fed the amount stated during the middle of the day when water temperatures are highest. (See Section XX.XX.XX)
- ***Clean fish tank glass.***
- The front of the fish tanks should be cleaned daily to avoid the build up of algae. Algae will utilise the nutrients and oxygen within the water, which is bad for fish health and plant growth. This task should be conducted with the aid of a magnetic scourer to increase efficiency and quality of work.
- ***Check pH Level and record***
- The pH of the system is a key indicator of system health and as a result should be checked and recorded daily. If the system is healthy the pH will gradually decrease. If the system is unhealthy the pH will gradually increase.
- ***Full walk around of aquaponic system, inspecting ALL joints (inc. roof joints) for leaks and any other issues whilst system is ON.***
- Another midday walk around should be conducted to inspect the system for leaks, ensuring the system is operating safely and correctly.
- ***Check for splashing in window bags and remedy if necessary.***
- It is an ongoing task to check that the window bags are not spraying out water to reduce water loss within the system and reduce maintenance/mopping.
- ***Ensure all 4mm hose outlets on roof are flowing freely and attend to the ones that aren't.***
- Due to the risk of these pipes becoming blocked they should be checked again around the middle of the day to ensure all are flowing. If all are flowing then no action is needed.
- ***Remove airlocks at every outlet valve***
- The potential of airlocks within the system is high so every outlet valve should be turned off and straight back on to allow trapped air to leave the system. This should be done several times to be sure that all the air has escaped. This includes the valves at the top of the filtration unit, window system and on the roof. It is very important this is completed daily to ensure the health and well being of system by allowing as much water to flow as possible.

Please note this task does not include the valves associated directly with the pumps. Closing these will affect water flow through the system and may cause damage to the pumps. (See 'Pump Valves' for details).

A.1.2.0.2 End of Day Tasks

End of day Tasks: The following tasks are required at the end of each day. (Inc. weekends)

- ***Remove all uneaten food from fish tanks.***
 - If uneaten food is left within the tanks it can quickly raise the ammonia level of the water, which is extremely bad for the fish. Rotting food within the tank can also lead to the growth of anaerobic bacteria. Both of these issues impact greatly on the health of the system and should be avoided at all costs.
- ***Remove airlocks at every outlet valve.***
 - The potential of airlocks within the system is high so every outlet valve should be turned off and straight back on to allow trapped air to leave the system. This should be done several times to be sure that all the air has escaped. This includes the valves at the top of the filtration unit, window system and on the roof. It is very important this is completed daily to ensure the health and well being of system by allowing as much water to flow as possible.

Please note this task does not include the valves associated directly with the pumps. Closing these will affect water flow through the system and may cause damage to the pumps. (See 'Pump Valves' for details).
- ***Clean out all lengths of 4mm black hose on roof.***
 - A final check should be made at the very end of the day to ensure all 4mm hose sections are flowing with water, ensuring that all plants are receiving water and that the fish are receiving as much water as possible.
- ***Check bilge pump in window sump is operating correctly.***
 - The risk of the float valve changing throughout the day is low but to give piece of mind and the confidence to walk away and leave the system running over night, the float valve should be checked. The operator should allow the sump located at the bottom of the window system to fill and drain several times to be satisfied with the operation of the bilge pump.
- ***Check all air stones are operational in each fish tank and ionisation tank.***
 - The named member of staff should sign off that each air stone is operational in each tank and also within the ionisation tank. If the air stone is not functioning correctly it could indicate that the air stone has cracked or the airline is bent, folded or blocked and should be replaced immediately.
- ***Check all fish tanks are receiving water from the roof.***

- The return pipe work from the roof has been designed in such a way that every tank receives a fair share of water. Although this is the case, slight movements in pipe work during feeding/maintenance can affect this so should be checked daily.
- **Final full walk around to ensure all work is completed to high standard and safe to be left overnight.**
- A final walk around at the end of the day will again, ensure the continued running of the system with greatly reduced chance of incident.

A.1.2.1 Weekly Tasks

Weekly tasks: The following tasks are to be conducted at the beginning of every week. All tasks should be conducted whilst the system is OFF.

- ***Chemical water tests.***
 - It is important to note that although the Siemens system monitors some aspects of the aquaponic system it does not monitor everything. It is important to conduct water tests on a weekly basis and the information be recorded on the 'Chemical Test' data sheet. These checks include testing the ammonia levels in the water, the nitrite levels within the water and the nitrate levels in the water.
- ***Inspect sumps for wear or damage.***
 - It is important that all three sumps be checked for wear and tear on a weekly basis. A primary inspection of the three sumps will identify any damage that may have occurred during the week. This damage, if identified early, can be rectified whilst the sumps is empty during the next task. The linings of the sumps are most vulnerable to damage whilst work is being conducted on them and caution should be employed at all times. This inspection will greatly reduce the risk of leaking, leading to water loss from the system and heightened maintenance.
- ***Clean sumps, remove water, dry, repair if required and refill***
 - Due to the nature of the sumps, they hold large volumes of slow moving water. As a result, solid waste can fall out the water easily in these places and line the edges and bottom with dirt. This solid waste needs to be removed weekly to avoid the growth of anaerobic bacteria and to ensure the health and well being of the system and the people working on it and around it. It is important to remove as much water as possible from the sumps before conducting the work. This includes using a wet vacuum towards the end to leave the sump empty. A deep clean must take place and approved substances may be used but only when absolutely essential to complete the task. The uses of substances should be reduced where possible to ensure the well being of the living things within the system. After the sump is clean and dry, any repairs can be conducted. It should then be refilled with fresh water. This task also doubles up as a small water change, which is good for the system.
- ***Clean window bags inside and out.***
 - The window bags are also a place for solid waste settlement. The mesh bags containing media ball and crops should be removed, the inside and outside of the grow bags should be cleaned with fresh water and then the mesh bags reinstated afterwards. To restrict the flow of dirty water into the sump, the return gutter should be blocked and emptied after each window is completed.
- ***Repair any broken joints on window bags with silicon.***
 - The white downpipes contained within the window bags are extremely fragile and subject the damage. As a result the pipes can work free which leads to spraying water. Whilst the system is off, all damaged pipes should be fixed and left to cure.

- ***Clean NFT channels***
 - Due to the shallow fall of the NFT channels, this is another place in which solid waste can settle out. To reduce the growth of anaerobic bacteria and ensure the well being of the system as well as the people working on it and around it, the NFT channels should be cleaned weekly. This includes the full removal of the NFT lids including the crops within them to allow full access to each channel. The channels should be cleaned from the lowest point up to highest point, as well as each channel being blocked off whilst this work is occurring, to prevent dirt migration into the fish tanks.
- ***Clean every side of fish tanks***
 - Although the front pane of glass is at most risk of harbouring algae and dirt, the sides will also accumulate waste along with other things, which need to be wiped off. The daily front glass cleaning with weekly full glass clean will ensure the wellbeing of the fish and the system.

A.1.2.2 Monthly Tasks

Once a month tasks: The following tasks are to be completed at the start of each month. All tasks should be conducted whilst the system is OFF.

- ***Change first set of 10mm clear hose atop of window system for second set.***
 - Due to the outlet hose sections at the top of the window systems being clear they are subject to algae growth. As mentioned earlier algae will utilise available oxygen and nutrients within the water for its own prosperity, taking them away from the plants and fish. The sections of hose therefore need to be changed every month to restrict this growth and replaced with clean pipe work.
- ***Place outlet bungs into the new sections of 10mm clear hose.***
 - The bungs need to be taken out of the dirty algae pipe work and placed into the new set and connected onto the outlets to ensure the pressure is equalised across each column of bags within each window.
- ***Clean and dry first set of 10mm clear hose ready for next months change.***
 - The old pipes will need to be placed in boiling water to kill the algae and if needed an approved substance can be used as weak solution within the boiling water to aid cleaning. The pipes must then be sufficiently dried and placed in a clean dry place ready to be swapped back at the beginning of the next month.
- ***Change first set of 4mm black hose and manifolds on roof for second set.***
 - As mentioned previously the 4mm black hose lengths on the roof are prone to solid waste build up due to their small diameter. The second set of 4mm hose sections should replace these to allow free flow of water. The manifolds are of a slightly smaller diameter than that of the 4mm pipe so these also need replacing on a monthly basis to ensure the ability of water to move freely to the roof NFT system and into the fish tanks.
- ***Clean and dry first set of 4mm black hose and manifolds ready for next months change.***
 - The old pipes will need to be placed in boiling water to kill the algae and if needed an approved substance can be used as weak solution within the boiling water to aid cleaning. The pipes must then be sufficiently dried and placed in a clean dry place ready to be swapped back at the beginning of the next month.
- ***Disassemble all push fit components, deep clean and reassemble.***
 - Push fit pipework is used to get water out of the fish tanks and also used as the return pipe work to the fish tanks from the roof. As the product is easy to connect and disconnect the entirety of the push fit system should be taken apart and scrubbed monthly. This is again to reduce the build up of solid waste, reduce the growth of

anaerobic bacteria and to ensure the well being of the system and the people around it.

Please note: The location of each and every pipe should be noted so that the system can be successfully reconnected. To clean a section one at a time and replace it as soon as it has been cleaned is advisable to avoid complications

- ***ALL joints to be inspected in detail and fixed/tightened where required.***
- Although daily checks are conducted, at the beginning of every month, each and every joint should be inspected for strength and robustness. At the end of the task there should no drips or leaks at any point within the system.

A.1.2.3 Quarterly Tasks

Quarterly Tasks: These tasks should be completed every three months and recorded, with any additional information detailed.

- ***Deep clean of ALL piping***
 - Solid waste will manage to settle out within all the pipes even though they have fast moving water flowing through them. To restrict the build up of waste the ENTIRE plumbing network of pipes should taken apart, cleaned and replaced. As with the push fit cleaning, it is advisable to clean components one at a time and replacing it in its original position as soon as it has been cleaned. This will avoid confusion of component location and allow the system to be re-commissioned successfully after this work has been completed. Warm water in a weak solution of approved substance is advisable to aid in the cleaning process.
- ***Deep clean of ALL filtration pods***
 - Every three months, the media balls within the filtration pods, as well as the filtration pod itself need to be rinsed out. The filtration pods are designed to collect solid waste in an effort to collect food for the worms located within them. Although they are designed in this way the solid waste cannot be left within the system too long. This entails the washing of media balls and filtration pod under fresh running water only. The bacteria and worms want to be kept alive so only cold water should be used. Absolutely no substances should be used.

A.1.2.4 Annual and Additional Tasks

A.1.2.4.0 Annual tasks:

These tasks should be completed on an annual basis and recorded, with any additional information detailed.

- ***Full shut down, deep clean and restart (please refer to '4.0 Deep Clean')***

A.1.2.4.1 Additional tasks:

These tasks are without time frame but should be completed as and when required, with any additional information detailed.

- ***Clean fish net after use.***
 - It is important that each fish species has its own dedicated net to avoid contamination between fish species (ideally one net per tank). These nets should be cleaned and left to dry after every use to reduce the risk of contamination.
- ***Fish tanks deep clean***
 - After the last fish has been harvested from a tank it should be emptied and deep cleaned, including the fish tank substrate. This is to avoid contamination from one harvest of fish to the next and from one species to another. This entails the entirety of the water to be removed from the tank and the substrate removed to be cleaned. Twisting the return pipe vertically upwards will stop fresh water entering the tank. The substrate should be rinsed under fresh running water and cleaned in boiling water to sterilise them. Whilst the substrate is out, the entirety of the glass fish tank can be cleaned internally utilising a weak solution of approved products. The substrate and tank should be left to dry and only then should the substrate be placed back into the tank and the tank allowed to refill from the roof
- ***NFT Channel deep clean***
 - After the harvest of crops from the NFT system the channels should be deep cleaned and dried ready for the introduction of new crops. The end of the channels should be blocked up to avoid the migration of waste into the fish tanks and cleaned from their lowest point to their highest point.
- ***Washing of media balls***
 - After crops are harvested from the window system the mesh bag should be removed from the grow bags and the media cleaned. As with the filtration pods there are beneficial bacteria contained within the media, which are essential to the success of the system. Hence, no substances should be used and the media, plus the mesh bag, should be rinsed clean in fresh cold running water. The two should then be reinstated and planted with a new crop.

A.1.3 Summary of Poultry tasks

ATTENTION!

The named member of staff should complete all the tasks listed below and should not be performed by others unless accompanied by the named member of staff.

A.1.3.0 Daily tasks

- *Wash Drinkers and refresh water*
- *Wash and refill Feeders Check for eggs. (Twice Daily)*
- *Check the coop for smell of ammonia and remove any large droppings in the nest box*
- *Refill the Grain ball with corn*
- *Observe the hens for approx 30 mins. Watch for signs of injury, illness, behavioural changes or bullying*
- *Visual checks to assess health and behaviour of bees. (See Section 3.4 Bees)*

A.1.3.1 Weekly Tasks

- *Clean Hen Coop & check for damage or signs of infestation*
- *Wash Feeders and drinkers thoroughly*
- *Check for signs of rats and other*
- *Check hens for lice and mites*

A.1.3.2 Monthly Tasks

- *(See Section 3.3.4.4 Month-by-month care plan)*

A.1.3.3 Annual Tasks

- *Clip Wings*

A.1.4 Poultry Tasks in Detail

A.1.4.0 Daily Tasks

Morning tasks: The following tasks are required at the start of each day. (Inc. weekends)

- ***Wash Drinkers and refresh water.***
 - Empty the drinkers of any remaining water. Rinse out the main compartment and wipe the underside and outside of the drinkers with a solution of warm water and antibacterial wash. Rinse thoroughly and dry. Refill the drinker with fresh cold water from the tap.

DO NOT use any cleaning products that contain PHENOL, as this is poisonous to poultry.

DO NOT fill drinkers with water from water butts as it may have been fouled by other animals or contain poisonous algae or other disease.
- ***Wash and refill Feeders (See Section 3.3.4.0.1 Method and Section 3.3.3 Feeding)***
 - Inspect the feeders for debris, damp mould and any other contamination. If the feed is damp it will likely clump. If the feed is damp or contaminated empty the remaining contents. Wipe the underside and outside of the feeders with a solution of warm water and antibacterial wash. Rinse thoroughly and dry. Refill or replenish as required with fresh feed.

DO NOT use any cleaning products that contain PHENOL, as this is poisonous to poultry.
- ***Check for eggs.***
 - Ensure all birds are clear of the coop before approaching the Nesting Box. Open the external lid of the Nesting Box and visually inspect for eggs. Carefully remove eggs from the nesting box and store appropriately.
- ***Check the coop for smell of ammonia and remove any large droppings in the nest box.***
 - When checking for eggs, check the nesting box for any large droppings and remove if present. Check the main house by ensuring all birds are clear of the coop, lift the roof hatch and check for a smell of ammonia or any visual indications of damp bedding. If this is present, the coop should be cleaned immediately.
- ***Refill the Grain ball with corn. (See Section 3.3.3 Feeding)***
 - Collect the Grain Ball from the chicken run. Empty any remaining corn onto the grass and remove any visible contamination. Pull apart the two sections of the ball, ensuring not to break the elastic ties. Using one half of the ball as a scoop, fill the ball with fresh corn. Close the ball and place it back within the chicken run.

- **Observe the hens for approx 30 mins. Watch for signs of injury, illness, behavioural changes or bullying.**

Particular signs to check for are:

- *Changes in colour, in particular the face and combs*
- *Foamy, watery or swelling of the eye*
- *Loss of feathers*
- *Ruffled feathers*
- *Lethargy*
- *Coughing, Gasping, Sneezing or Rattling*
- *A hunched appearance*
- *A noticeable decrease in water and food consumption*
- *A noticeable increase in water and food consumption*
- *Diarrhoea*
- *Rapid weight loss*
- *Extended neck and frequent swallowing or floppy neck*
- *Sores*
- *Excessive scratching*
- *Swollen legs or raised scales on the legs*
- *Lameness*
- *Inflammation*
- *Any signs of discomfort or bleeding*
- *In the event of a suspected injury or illness, a local vet should be contacted immediately.*
(See section 3.3.5.0 for vets details)

- **Visual checks to assess health and behaviour of bees. (See Section 3.4 Bees)**

A.1.4.1 Poultry Weekly Tasks

Weekly tasks: The following tasks are to be conducted at the beginning of every week.

- ***Clean Hen Coop & check for damage or signs of infestation***

- Remove all muck and bedding from the coop and nest boxes. Use of a Hand Shovel is recommended. Remove the Droppings Board and remove any remaining bedding. Disinfect the coop with a proprietary poultry disinfectant, paying particular attention to the corners. Remove the perches and the partition in the nest boxes and disinfect. Rinse all elements with warm water, dry thoroughly and re-assemble. Layer fresh bedding across the bottom the coop, ensuring a full coverage. (This can act as insulation so you may choose to add more or less depending on the season, but always ensure there is a full coverage.) Layer fresh bedding (approx 1" thick) into the nest boxes.

DO NOT use any cleaning products that contain PHENOL, as this is poisonous to poultry.

- ***Wash Feeders and drinkers thoroughly.***

- Remove all remaining contents and disassemble if possible. Wash the INSIDE and OUTSIDE with a mixture of warm water, a mild first aid disinfectant and a small amount of washing up liquid. Use of a scrubbing brush is recommended. Rinse thoroughly with clean water to remove all traces of cleaning solution. Dry thoroughly and reassemble before refilling.

DO NOT use any cleaning products that contain PHENOL, as this is poisonous to poultry.

DO NOT fill drinkers with water from water butts as it may have been fouled by other animals or contain poisonous algae or other disease.

- ***Check for signs of rats and other vermin and take precautions as necessary.***

- Visually inspect for evidence of infestation such as gnawing or rodent droppings.

- ***Check hens and coop for lice and mites by parting the feathers at the base.***

- External parasites are organisms that usually feed on the blood or skin of the chickens. Attacks may be sudden, especially in the warmer months. Severe infestations can cause anaemia and sometimes death so it is important to check regularly.
- Visually inspect the coop for signs of mite infestation by searching the ends of the perches, in corners and along crevices of the coop. Mites are usually around 1mm in size and can be bright red to pale grey in colour.
- Inspect the birds for infestation by parting the feathers at the base. Focusing under the wings and around the vent/tail area, Lice will quickly scurry out of the light. Eggs often

look like clumps of granulated sugar around the base of the feather shaft and are difficult to remove.

- In the event of a suspected infestation, a local vet should be contacted immediately, advice on appropriate actions and treatments will be given. (See section 3.3.5.0 for vets details)

A.1.4.2 Poultry Monthly Tasks

Monthly tasks: The following tasks are to be conducted at the beginning of every month.

- *For Hens (See Section 3.3.4.4 Month-by-month care plan)*

A.1.4.3 Poultry Annual Tasks

Annual tasks: The following tasks are to be conducted at the beginning of every year.

- ***Wings of the Hens should be clipped.***
- Clipping the Hens wing is essential in preventing attempting to fly over the perimeter fencing. This should be done annually, and always by a professional.

A.1.5 Summary of Roof Garden Tasks

ATTENTION!

The named member of staff should complete all the tasks listed below and should not be performed by others unless accompanied by the named member of staff.

A.1.5.0 Daily tasks

Sweep Walkways

Inspect Chicken Coop

Inspect Bee Hive

Inspect all fencing

Check to ensure all fences are secure to the roof and free from damage.

Water the Lawn

A.1.5.1 Weekly Tasks

- N/A

A.1.5.2 Monthly Tasks

- N/A

A.1.5.3 Quarterly Tasks

- N/A

A.1.5.4 Annual Tasks

- N/A

A.1.6 Roof Garden Tasks in Detail

A.1.6.0 Daily Tasks

Daily tasks: The following tasks are required at the start of each day. (Inc. weekends)

- ***Sweep Walkways***

- Pathways should be swept once a day, in the morning and when required to keep walkways clear of gravel etc.

Following periods of heavy rainfall large puddles should be swept out to evenly distribute the water and encourage drying. Special effort should be made to direct water down the drainage pipe to avoid standing water.

- ***Inspect Chicken Coop***

- In winter months check to ensure chicken coop is secure to the roof and free from damage.

- ***Inspect Bee Hive***

- In winter months check to ensure the Beehive is secure to the roof and free from damage.

- ***Inspect all fencing***

- Check to ensure all fences are secure to the roof and free from damage.

- ***Water the Lawn***

- In summer months water the lawn. During one-off hot days 3-4 watering cans of water should be evenly distributed over the turf. During ongoing periods of hot dry weather it may be more labour-efficient to use a sprinkler system for 1 hour, 2 times a day.

A.1.6.1 Weekly Tasks

- N/A

A.1.6.2 Monthly Tasks

- N/A

A.1.6.3 Quarterly Tasks

- N/A

A.1.6.4 Annual Tasks

- N/A

A.1.7 Legionella Task list Summary

ATTENTION!

The named member of staff should complete all the tasks listed below and should not be performed by others unless accompanied by the named member of staff.

A.1.7.0 Daily Tasks

- *System inspection.*
 - *System component inspection.*
 - *Monitor and record water quality. (ie. pH, average tank temperature)*
- (Please See Appendix B01 Risk Assessment: Control of Legionella in Technical Food Systems)*

A.1.7.1 Weekly Tasks

- N/A

A.1.7.2 Monthly Tasks

- *Check operation of UV filters*
- (Please See Appendix B01 Risk Assessment: Control of Legionella in Technical Food Systems)*

A.1.7.3 Quarterly Tasks (to be completed by specialists)

- *Microbiological monitoring – total count*
 - *Microbiological monitoring – Legionella count*
- (Please See Appendix B01 Risk Assessment: Control of Legionella in Technical Food Systems)*

A.1.7.4 Annual Tasks

- *Full shut down, deep clean and restart (please refer to '4.0 Deep Clean')*
- (Please See Appendix B01 Risk Assessment: Control of Legionella in Technical Food Systems)*

A.1.8 Legionella Prevention Daily Tasks

A.1.8.0 Daily Tasks

Daily tasks: The following tasks are required at the start of each day. (Inc. weekends)

Daily Tasks

- ***System inspection.***
 - Visually inspect the internal condition of sump, tank, filtration beds, grow bags, NFT channels and water. Check for signs of:
 - Uncharacteristic microbial growth
 - Algae
 - Water leaks
 - Splashing
 - Blockages or restrictions.
- ***System component inspection.***
 - Visually inspect the condition of all components including filters, pumps and pipes. Check for signs of:
 - *Uncharacteristic microbial growth*
 - *Algae*
 - *Water leaks*
 - *Splashing*
 - *Blockages or restrictions.*
- ***Monitor and record water quality.***
 - Water chemistry should be monitored and recorded to track the risk of Legionella bacteria within the system and assess the general health of the system. The Siemens Control Panel can be used to monitor:
 - *Temperature*
 - *pH*
 - *Flow rate*
 - *Electrical Conductivity*

A.1.8.1 Monthly Tasks

Monthly tasks: The following tasks are required at the start of each month.

- ***Ensure UV filters are operational.***
- Although the UV filters are cleaned daily, as part of the Legionella prevention activities. It should be noted on a monthly basis that all UV filters have been inspected and functioning correctly.

A.1.8.2 Quarterly Tasks

Quarterly tasks: The following tasks are required every three months.

- ***Microbiological monitoring – total count***
 - Quarterly tests should be carried out by a specialist lab to establish the total count of microbiological organisms present within the water.

- ***Microbiological monitoring – Legionella count***
 - Quarterly tests should be carried out by a specialist lab to establish the total count of legionella bacteria present within the water.
 - ALL Microbiological testing should be carried out by a suitable professional body and recorded. (See C01)

A.1.8.3 Annual Tasks

Annual tasks: The following tasks are required at the beginning of every year.

- *Full shut down, deep clean and restart (please refer to '4.0 Deep Clean')*

A.2.0 Hardware

The following section will provide details on how the system functions and the functionality of each set of components. It will also provide additional details on the maintenance tasks that concern the specific areas seen below.

A.2.1 System schematics

A.2.1.0 Aquaponic Units

In essence, the aquaponic system within Irwell House is a collection of four units, which are connected via pumps and pipe work. These areas are defined as:

Fish tanks – The area in which the fish reside located on the second floor.

Filtration Mineralisation and Ionisation Unit (FMI) – The area in which most solid waste is filtered and ammonia conversion occurs located on the second floor.

Window Growing Area – Hanging Grow bags containing plants and located on the second floor.

Roof Growing Nutrient Film Technique (NFT) – Growing channels containing plants located on the roof.

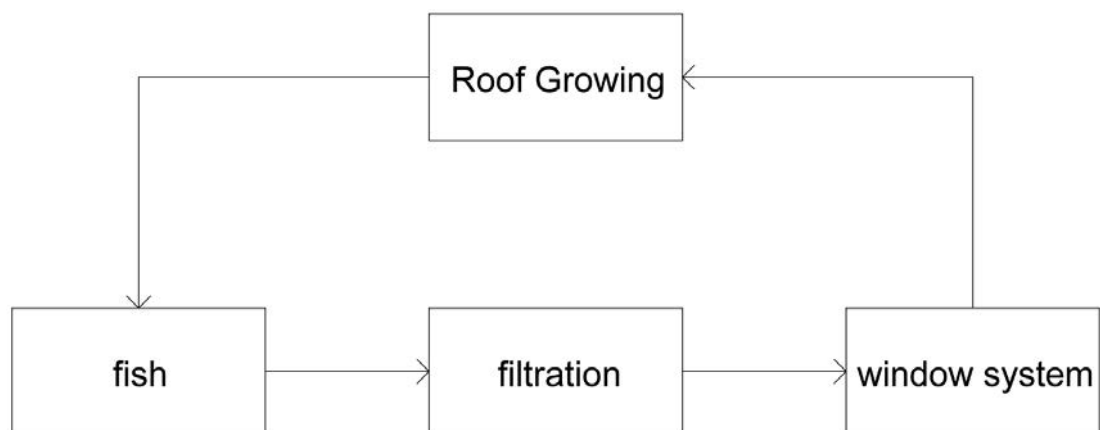


fig 1. Relative connectivity of the aquaponic units

A.2.1.1 Summarised explanation of system

The system contains 12 fish tanks, which at the point of writing this manual contained carp and tilapia. These twelve tanks all drain by gravity into a single sump. This water is then pumped to the top of the filtration unit, which contains 98 filtration pods arranged into 14 columns. Water moves through these filtration pods via gravity into a single sump. This water is then pumped to the top of the window growing system, which contains 150 grow bags arranged into five windows. This water is allowed to flow through the grow bags via gravity and collects in a single sump. The water from this sump is then pumped vertically to reach the roof. When the water reaches the roof it is pumped into 34 nutrient film technique (NFT) channels. From here the water flows down the channels via gravity and eventually is returned to the 12 fish tanks via gravity from the roof where it is divided equally into each tank. (See fig 2. For details.)

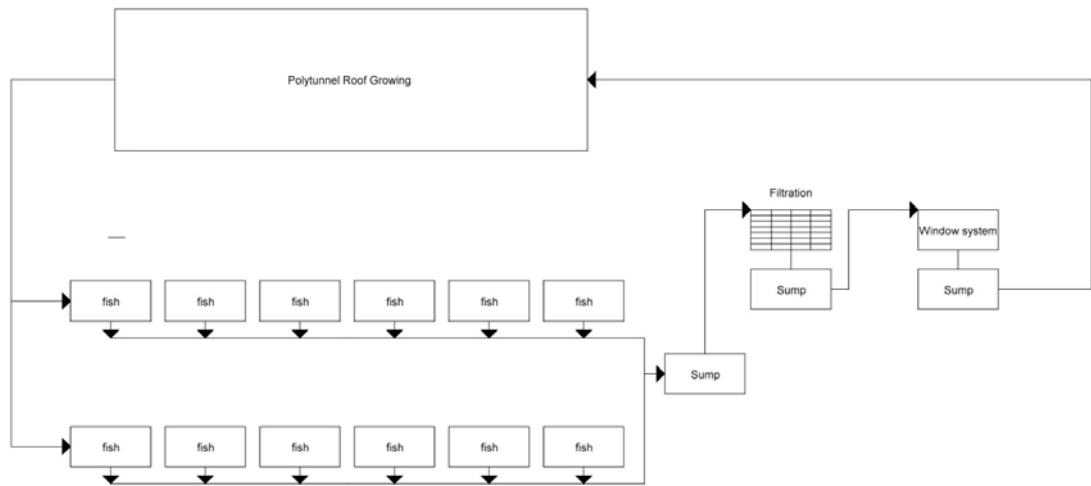


fig 2. Water flow schematic

The detailed schematic below shows the completed system at the time of writing the manual. Three tanks are shown in the schematic to represent a single side of the aquaculture lab (a four sided space surrounded by fish tanks with three tanks along each side) and to avoid complexity and confusion in the diagram. It can be seen that water travels from the fish tanks into a sump, then onto the filtration unit and into a sump, up to the top of the window bags and into a sump and then onto the roof and back to the fish tanks to start the cycle again.

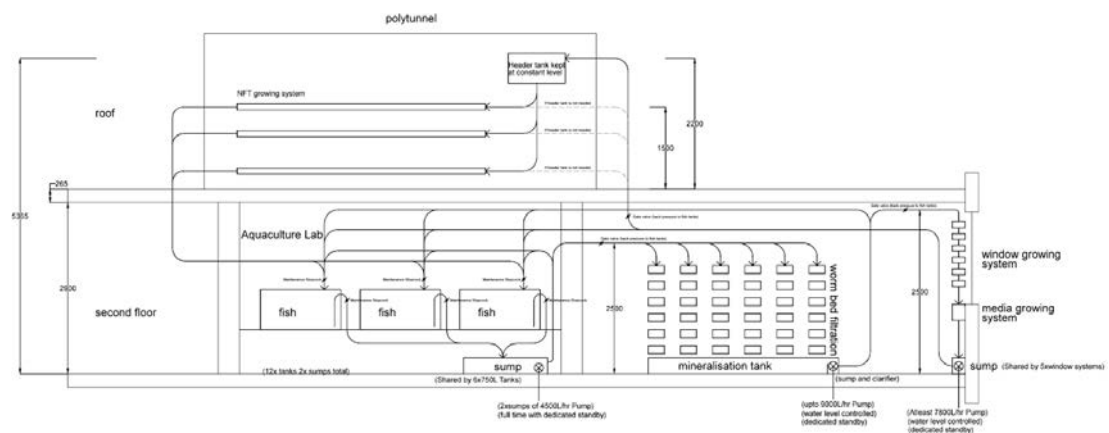


fig 3. Detailed Schematic of completed aquaponic system

A.2.2 Running the System

The following sections will give details on the different components of the aquaponic system located within Irwell House.

A.2.2.0 Primary Pumps

There are three primary pumps within the system; one Oase 21,000 pump in the fish sump, one Oase 21,000 pump in the filtration sump and one Oase 40,000 pump in the window system sump. The pumps govern the speed and pressure at which water is moved through the system. The pumps have all had their outer cowlings removed to allow them to sit lower in the water and to be connected in line.

The two Oase 21,000 pumps have 2-inch inlets and outlets. The Oase 40,000 has a 3-inch inlet and a 2-inch outlet.

The pumps should be checked daily for blockages to ensure the health of the aquaponic system and to minimise the risk of flooding.

ATTENTION!

Before ANY work is conducted on the pumps the system MUST be switched off on the Siemens panel by the isolator switch, the plug socket in which the pump is located MUST be switch off and pumps MUST be unplugged. Failure to do this could lead to significant injury. This is non negotiable and must be adhered to regardless of the views of the person or persons undertaking the work. Make sure the water is tipped out and allowed to drain from the pump before they are removed from the sump. This will reduce the amount of water that is lost from the system as also reduce maintenance.

A.2.2.1 Pump Filters

Each pump has a filter fitted, which restricts the movement of solid object moving into the pump housing. The filters on each pump should be removed and cleaned during daily pump maintenance. Blockages can lead to uneven flow between the three main pumps. Uneven flow will lead to uneven water movement. This can lead to either an inefficient system, impacting on the health of the living thing within it, or the retention of water in one of the sumps leading to an overflow. The system must be shut down at the beginning of every day to conduct these inspections.

A.2.2.2 Power Consumption

The system uses 1kW at the point of writing this manual. This value is minus the power of the heaters, which are variable.

A good indication of blockages within the system can be seen within the power consumption data displayed by the Siemens panel. If this value was to drop a significantly then a major blockage may have occurred. This blockage could be within the pump or within pipe work. This information can be found on '7.0' (page 7) of the Siemens energy monitor for the aquaponic system. The image below shows the information shown on '5.0' (page 5) of the Siemens energy panel, which represents the power consumption of pumps 1,2 and 3 respectively. Any major reduction in these values will indicate after which pump the blockage is.

ATTENTION!

This indicator will only give information on blockages under pressure from the pumps and will not indicate blockages within any pipe work not under pressure (ie. outflow from fish tanks, filtration pods, window bags, NFT channels or return pipe work to fish tanks)

ATTENTION!

During the writing of this manual tank heaters were added to the system. These will give a higher reading than specified at the beginning of this sub-section. To ensure the pump power information can be viewed accurately ensure the heaters are switched off at the Siemens panel to remove their readings from the total power consumption.



fig 4. Power consumption of pump 1, pump 2 and pump 3 respectively

A.2.2.3 Secondary pumps

The system contains a secondary Clark Hippo 4A bilge pump located within the window system sump. This pump is controlled via a float switch, which is directly attached to the pump. This pump is an additional safety feature to avoid flooding. The sump located as part of the window system is designed to fill and drain with the help of this pump.

The float switch is sensitive to disturbance. When the Oase 40,000 pump is removed daily to check for the angle of the float switch could be accidentally changed and may not operate as it once did. When the Oase 40,000 pump or Clark Hippo 4A pump have to be moved please ensure there is sufficient time afterwards to observe the sump fill and drain several times. This will allow the aquaponic system operator to determine that the float switch is working correctly. The sump should fill and turn on the Clarke Hippo 4A pump but should not overflow. When the sump drains the pump should switch off after a short period of time.

A.2.2.4 Pump Valves

Each pump has two valves. These determine the percentage of water that reaches the next stage of the system. One valve determines how much water is recirculated into the sump in which the pump is located. The other valve determines how much water reaches the next stage of the system. (Please refer to system schematic when determining the next stage of the system).

ATTENTION!

Never close both valves at the same time, as it will cause very high pressure on the electric motor and damage the pump. This action would also put high pressure on any joints between the pump and valves and could lead towards leaking or catastrophic pipe failure.

A.2.2.5 Sumps

A sump is a collection point for liquids at the lowest point within a closed system. The sumps within the aquaponic system allow many streams of water to flow into one volume and be pumped by a single pump. In the instance of the fish tanks, it is much more energy efficient to use a larger single pump to move water then to have twelve smaller pumps in each tank. The sumps are constructed from a natural rubber membrane, which due to its role within the system will become dirty over time. The sumps will need cleaning weekly to avoid the growth of anaerobic bacteria. Cleaning chemicals should be avoided at all times, as they will kill the beneficial bacteria within the system. When additional strength is needed to clean items within the system a weak solution of an approved substance can be used, but should be used sparingly.

ATTENTION!

Please exercise caution when conducting work on or around the sumps, as the membrane is fragile and easily punctured. If the sumps are damaged in anyway there is elasticated tape on site, which can be used to repair punctures, rips or cuts, once the sump has been entirely emptied, cleaned and dried.

A.2.2.6 Filter Pumps

There are two filter pumps located in two of the twelve fish tanks. These are utilised as a precautionary measure to ensure good water quality within the fish tanks. If a tank experiences a lower-than-average fresh water flow from the roof, the tank in question will exhibit poor water quality, seeming cloudy. The two filter pumps should be located in the tanks, which are deemed to have the poorest water quality. The filter pumps will fill with solid waste and as a result should be cleaned daily to ensure the solid waste is not kept within the tanks.

When removing the filter pumps please ensure the pump is switched off and allowed to drain sufficiently atop of the tank before removing it from the aquaculture lab. This will minimise water loss from the system and as a result, reduce maintenance.

A.2.2.7 UV Filters

There are three UV filters within the aquaponic system. These are used to eradicate the movement of bacteria between the different units of the aquaponic system and primarily to avoid the growth of

Legionella. Although the risk of growth of Legionella and Legionnaires Disease is very low (see Appendix B01) they have been included as a precautionary measure. As these UV filters are an essential component to the prevention of disease in and around the aquaponic system they should be removed daily and cleaned. This is to ensure they are working at their highest efficiency possible on a daily basis.

ATTENTION!

This work should only be undertaken by the named member of staff on the front of this manual who is confident in their abilities to disconnect and reconnect the pipework, remove the unit from the wall and reattach it, remove vital components such as the glass UV bulb and glass encasement and reassemble the unit as it was manufactured.

A.2.2.8 Filtration Mineralisation and Ionisation (FMI) Unit

The filtration unit within this aquaponic system uses an experimental approach, which has been carefully designed to provide both biological and mechanical filtration.

This FMI unit is essential for the health of the aquaponic system as it is the home to the majority of the bacterial population, which will convert the Ammonia of the fish into accessible Nitrate for the plants as well as providing a place for worm colonisation.

The unit is comprised of 98 filtration pods arranged into 14 columns. Each column is fed by a 20mm valve, which can all be altered to achieve equal pressure across all 14 valves or to shut down a column at a time for maintenance/inspection. Water flows through the pods utilising gravity and ends up in a sump. This sump acts as ionisation tank, which is again experimental in its use within the aquaponic system. It is hoped that this sump will encourage the growth of aerobic bacteria, through the use of eight air stones, and further break down solid waste to be utilised by crops within the system. The success of this unit is unknown at the time of writing this manual.

Although every precaution has been taken to prevent the blockage of the valves, this is something that should be checked daily to ensure every column is receiving an equal share of the water flow. The ability of water to move freely and vertically through the system must also be checked daily to ensure there are no blockages within the pods, which could lead towards splashing and/or flooding.

A.2.2.9 Clay Media Balls

The media used within the filtrations pods is the key to efficient water filtration. The use of media within the FMI bank allows the solid waste from the fish tanks to be removed from the water as it passes through the vertical filtration pods as well as providing high surface area for bacteria to colonise. It is recommended that Expanded Clay Balls be used only within the FMI.

Decreasing the size of the media as the water flows vertically increases the efficiency of the filtration.

8mm – 12mm Expanded Clay Balls for the top 2 rows.

4mm – 10mm Expanded Clay Balls for the middle 3 rows.

4mm – 8mm Expanded Clay Balls for the bottom 2 rows.

A.2.2.10 Window system

The window growing system contains of 150 bags over 5 windows with 30 bags in each window. Each window contains 10 columns of 3 bags. At the top of each column is a clear plastic pipe which house a bung to control pressure. The pressure is equally spread across the columns of grow bags via these bungs. As a consequence these bungs should be checked daily to ensure they are still situated firmly within the clear pipes. Failure to check this could lead to a bung coming free and water flow increasing. This increase of water flow could lead to overflowing or significant splashing. The ten outlets with bungs are controlled via a main central 20mm valve situated in each respective window. These valves allow the equalisation of pressure across each window and provide the ability to shut down a window for maintenance/inspection. These valves should be inspected every day for blockages and also in line with the instructions to avoid airlocks. (Please refer to the 'Airlock' section.)

The clear piping at the top of the grow bags should be changed for a new set every month to prevent large algae build up. This build up of algae will lead to a restriction in the diameter of the pipe and restrict flow. Once the old set that have been replaced, they can then be cleaned and dried, ready to replace the other set in a months time.

The grow bags themselves are made from UV stable silicone which allows them to sit in the window without deteriorating over time due to sunlight. They comprise a mesh insert that holds the growing media. These mesh inserts allow for easy removal of growing media from the growing bags for harvesting/planting and maintenance. The grow bags themselves should be cleaned inside and out (including white pipe) on a weekly basis to prevent the build up of dead spots/grime on which anaerobic bacteria can thrive. This will result in the mesh insert plus growing media and crop to be removed from the grow bag whilst this occurs.

At the bottom of each window system there is a water return system that takes water to a central sump ready to be pumped to the roof. This system comprises of angled guttering plus 50mm return piping. The guttering has proved itself as a collection point of dirt and grime. The guttering needs to be cleaned on a daily basis because of this to help prevent the growth of anaerobic bacteria. There is also a gutter debris collector located at this point. This prevents the movement of solid matter into the window sump, which reduces the risk of pump blockages. This need to be cleared daily to ensure water is free to move through the system and reduce the chance of flooding.

The return pipe work is arranged in such a way that the middle window has its own return pipe and the two windows on the right share a return pipe and the two windows on the left share a return pipe.

The sump associated with the window system is subject to the migration of growing media into its water volume, which can cause blockages. This pump should be checked rigorously every day for growing media to prevent uneven flow.

ATTENTION!

Before any work is carried out on any of the five window growing systems the valve of the specific window should closed off to reduce water loss from the system. Measures should be taken to restrict the movement of water into the return pipe work. This is to prevent the dirt from the window bags or guttering entering the sump and as a consequence infiltrating the rest of the aquaponic system. The dirt needs to be removed from the system not simply allowed to move onto the next stage and settle out elsewhere. This is crucial for the health and well being of the system and the people who work around it.

ATTENTION!

Before ANY work is conducted on the pumps the system MUST be switched off on the Siemens panel by the isolator switch, the plug socket in which the pump is located MUST be switch off and pumps MUST be unplugged. Failure to do this could lead to significant injury. This is non negotiable and must be adhered to regardless of the views of the person or persons undertaking the work. Make sure the water is tipped out and allowed to drain from the pump before they are removed from the sump. This will reduce the amount of water that is lost from the system as also reduce maintenance.

A.2.2.11 Rooftop NFT System

The NFT system on the roof comprises of 34 angled growing channels. These channels ensure that water is supplied to the vast majority of crops within the system as well as the eventual return to the fish tanks.

The pressure equalisation at the top of the system is much more predictable and as a result does not comprise of as many valves as are seen in the other units of the aquaponic system. There are, however, two release valves, which allow the easy removal of air from the water feed to the roof. The NFT system is subject to regular airlocks, which need to be removed on a daily basis. If the airlock is allowed to increase the water pressure to the roof can become very low. If little water reaches the roof then the fish do not receive any fresh water. This diminishes the water quality for the fish and can lead to fish death or at best increased fish tank cleaning. The reduction in water pressure also prevents the crops receiving water, which can hinder growth or lead to plant death. The two main 20mm valves on the far left and right of the NFT system need to be kept open at all times to prevent the build up of air. To avoid the flooding of the NFT system these should be open to between 50% and 75%. Opening the valve up to 100% for more than a few seconds will lead to water loss from the system. These outlet valves should be checked at the beginning and end of every day to ensure there is sufficient water flow through them. A reduction in water flow indicates a blockage or an airlock. (Please see the 'Airlock' section for details.)

As the water from the window sump feeds the roof, there is a requirement to check for the migration of growing media in all the outlets on the roof. The small stone like media balls can get trapped behind the main outlet valves and also behind the black manifolds to which the 4mm hoses are connected. At the beginning of every day when the system is switched off the outlets on the roof should be disconnected and the manifolds and outlet valves cleared of any all debris. These actions will prevent debris build up and also promote the free movement of water through the system, which will ensure the ecosystem remains healthy and successful.

At the end of each NFT channel there is a 2 inch net pot which breaks the surface tension of the water allowing the water to fall evenly through the round hole but also acts as a debris collection point. These pots should be emptied at the beginning of every day to allow free movement of water and avoid water loss from the system.

There are 2 x 4mm hose outlets into each NFT channel. Due to the small diameter these pipes are subject to blocking through dirt build up. These pipes must be checked and unblocked at the beginning, middle and end of day on a daily basis. This is to ensure that each growing channel is receiving all the water it needs, leading towards the best crop growth, and ensuring the fish tanks receive as much fresh water as the system will allow.

It is suggested that much like the window system, the 4mm hoses and the manifolds be replaced on a monthly basis. In which time the old set can be washed, cleaned and dried ready to replace the other set in a months time. This ensures the reusability of components, which minimises cost. The 4mm hose can be found on site for when this needs to occur.

Due to the relatively shallow angle of the NFT, solid waste can settle out. Solid waste will reduce the efficiency at which plant roots can take up nutrients. It is important to clean the NFT channels on a weekly basis to avoid the build up of waste, increase plant efficiency and reduce the buildup of dead spots and anaerobic bacteria.

ATTENTION!

To prevent water losses please ensure the system is switched off before any inspection of valves or manifolds is undertaken. The system should also be switched off to conduct the cleaning of the NFT channels. Failure to do this will send the dirt directly into the fish tanks causing distress to the fish.

A.2.2.12 Airlocks

Airlocks will appear within the system as a result of pumps switching off due to the Siemens control system. Airlocks will restrict the flow of water through pipe work, which will hinder the system.

To resolve this issue, turn all valves within the system off and immediately back on one at a time. This action helps force air bubbles towards outlets where they can escape. This is noted as one of the daily tasks of the system. This action is limited to all outlet valves and should not be applied to the valves directly associated with pumps as this will create immense pressure of the pumps and reduce their reliability.

A.2.2.13 Piping and Joints

There are two main types of pipe used within the system that are under pressure from pumps. The pipe used predominantly is black, nylon-reinforced flexi-hose that comes in a range of diameters, which include 20mm, 32mm, 40mm and 50mm. The other form of pipe work is green and white reinforced and semi-rigid piping. This is used where pressure is high. This pipe exists within the system at 40mm and 50mm diameters.

There is 10mm hose used in the outlets of the windows and 4mm hose used in the outlets of the NFT system plus 32mm and 50mm push fit piping used to and from the fish tanks.

Where ever black nylon-reinforced flexi-hose is used there will be PTFE wrapped around the plumbing component to give a tight fit and a double wire clamp to secure the connection.

The green and white reinforced semi rigid piping has a slightly smaller internal diameter and as a result is a much tighter fit so does not require PTFE tape. It is connected to components using traditional jubilee clamps.

At the beginning of everyday when the system is fully operational there should be a full walk around and inspection to check for leaks, drips or any anomalies in the systems operation. This includes a detailed survey of every joint within the system starting at the fish tanks and ending back at the fish

tanks. If there are leaks found during this inspection the system should be switched off and the joints in question be fixed. If any anomaly is identified and not dealt with immediately, it could lead toward a catastrophic failing in the joint in the future.

ATTENTION!

Only the named member of staff who has previous experience of plumbing should conduct the work on piping or joints.

A.2.2.14 Fish Tanks

The fish tanks in the aquaponic system are 150cm long x 75cm high x 75cm wide. There are 12 in total and hold approximately 750 litres each. In total there is nearly 9,000L held between all fish tanks. The fish tanks house the most complex living things within the ecosystem so should be cared for and monitored at all times.

Each fish tank has a return feed from the roof, which is supplied by a 50mm push fit pipe system. The return water is equally distributed between the tanks by changing the angle of the 50mm return pipe. A higher angle will see a larger volume of water entering a tank, but less water will feed into the tanks after it in the piping series. The equal distribution of water to the tanks is crucial to the well being of the fish. At the beginning of every day each fish tank should be checked to ensure it is receiving a steady flow of water. If the water to a single fish tank needs to be stopped for any reason, the grey push fit return pipe should be twisted vertically upwards, which will stop the flow of water to the tank in question. When doing this, the pipe should be returned to the tank as quickly as possible to ensure the water quality of the tank remains high.

The front glass panel of the tanks should be cleaned daily to prevent the build up of algae, which will use available nitrate and oxygen within the water, leaving less nutrients for the crops and less oxygen for fish. It will also keep the fish happy and healthy to live in a clean environment. The other sides should be cleaned weekly.

The fish should be fed in accordance with the feeding schedule (see SECTION xx) and any waste food that is not eaten should be removed from the tanks at the end of the day to avoid rotting.

Tanks Supplier: (Recommended)

Tank Dimensions : 1500mm x 750mm x 750mm

Midland Aquatic Imports
Unit 4, Harvey Works Ind Est
Shelah Road
Halesowen
West Midlands B63 3PG

Telephone: 0121 550 0148
info@midlandaquatics.co.uk

A.2.2.15 Tank Lids

At the time of writing this manual five tank lids had been constructed to cover the five tilapia tanks. The tank lids are used to retain higher temperatures within the tilapia tanks. Each tank is fitted with a heater and to maximise the efficiency and effect of the heaters, tank lids were manufactured. The tank lids are designed to negotiate all the equipment and obstacles present within the aquaculture lab by creating the smallest opening possible to minimise heat loss.

It is advisable to keep the lids on the tilapia tanks 24 hours a day except for when all the glass sides are cleaned once a week, during fish harvests and full tank deep cleans when the tanks are free of fish.

A.2.2.16 Outflows

The outflow pipes are white vertical pipes situated within the fish tanks. These take solid waste and water out of the tanks to maintain water quality. Sometimes these pipes become dislodged due to fish swimming into them so should be checked every morning to ensure they are vertical and placed firmly within the outflow tank connector.

If the 'T' joint at the top of the pipe is purposefully blocked it will operate as a siphon, removing most of the water within the tank. This greatly decreases the amount of effort needed to drain the tanks to allow for cleaning. This can be achieved by using a 32mm socket-end to plug the hole and then a large amount of water from a bucket being dropped in. The sudden extra addition of water will engage the siphon and the socket end will ensure no air enters the siphon, which would break it.

Upon the harvest of the whole tank, the siphon should be engaged to allow for the full deep clean of the tank (including substrate) ready for the next batch of fish.

ATTENTION!

Failure to clean the tanks after each full fish harvest will increase the risk of contamination from one fish species to another which could lead to fish suffering and possibly fish death.

A.2.2.17 Air stones

Within each tank is an air stone. These are porous manufactured stones, which are connected to air compressors and deliver fresh oxygen to each tank. The air stones ensure high dissolved oxygen levels within the tank and the health and well being of the fish. These should be operational at ALL times. Failure to ensure the air compressors and air stones are operational at ALL times will lead to distress of the fish and fish death. These should be checked at the beginning and end of every day.

At the time of writing this document there were also eight air stones in the ionisation tank at the bottom of the filtration unit. These air stones are located here to promote the growth of aerobic bacteria and minimise dead spots and the associated growth of anaerobic bacteria. These should also be checked at the beginning and end of every day to ensure their continued operation.

A.2.2.18 Tank Temperature probes

Within each tank there is a temperature probe, which is connected to the Siemens monitoring and control system. These readings can be accessed via the HMI provided by Siemens. Monitoring tank temperatures is crucial to the well being of the system. Extreme low temperatures are to be avoided to maintain the health of the fish and high temperatures are to be avoided due to the risk of legionella growth (see appendix B01 for legionella report).

A.2.2.19 pH Probes

Each pH sensor is located within its own water bath located within each of three sumps. It is important that all the pH sensors be kept wet at all times. Failure to ensure this could render the probe useless if it is allowed to dry out. It is also important to check that all the baths have water running through them to ensure the data being collected and shown on the Siemens HMI is accurate. If water is not flowing through any of the pH baths, please repeat the actions for removing air locks.

A healthy aquaponic system will become increasingly acidic over time, this gives information to the named member of staff as to the health of the system. A gradual lowering of pH will indicate the presence of needed aerobic bacteria whilst and gradually increase in pH will indicate the presence of anaerobic bacteria, something which needs to be avoided.

A.2.2.20 Flow Rate Probes

At the time of writing this manual the flow meters supplied by Siemens were still not operational. The flow rate through the system wants to give each fish tank a water change once per hour. With the fish tanks holding close to 9,000L it is hoped that the system will move close to 9,000L per hour.

A.2.2.21 Evaporation

Where possible, steps have been taken to encapsulate and cover water flow to minimise water loss. To reduce water loss is to reduce water use, which in turn will reduce running costs. It is important to consider evaporation, especially during the hotter months.

A.2.2.22 Filling the system

The system will need filling frequently to ensure the wellbeing of the system. The system runs in such a way that if the fish tank sump ever runs dry and water stops running through the filtration unit, it indicates the system is low on water. The water usage of the system depends on a number of factors including temperature, biomass in system, splashing and flooding. As a consequence the water usage of the system cannot be calculated to a daily need. The filling of the system should be recorded on the water filling form found at the rear of this document.

ATTENTION!

A timer should always be set when filling the system to avoid the risk of overflowing and flooding.

A.2.2.23 Electrical Conductivity Probe

A single electrical conductivity probe resides in the pH bath located at the window sump. This probe gives information on the available ions within the water that are accessible to plants. The information is viewable of the Siemens HMI.

A.2.2.24 Switching the System Off

The system will be switched off at least once a day for maintenance and inspections. It is important to note that when the system is operational all the pipe work, NFT channels, filtration pods and window bags are filled with water. When the system is switched off this water where ever it is located will end up in a sump. It is important to check that there is enough space in the sumps to accommodate this extra water. The main sump to check is the fish tank sump as there is a huge volume of water on the roof still left to return to the fish tank sump upon turning the system off. Even in an emergency it is crucial to ensure there is enough space in the fish tank sump to accommodate this extra water. Failure to do will lead to an increased risk of flooding.

It is a good general practice to gradually turn the system off one pump at a time starting at the pump located in the sump that contains the least water, and ending with the pump located in the sump that contains the most water. This allows the pump which is located in the sump with the most water the time to move some of that water into a sump with less water, greatly reducing the risk of flooding.

A.2.2.25 Switching the System On

Much like switching the system off it is best to turn the system on gradually but this time starting with the pump located in the sumps with most water and working towards the pump located in the sump with the least water. This allows some time to spread the water out equally and again, reduce the risk of flooding.

A.2.2.26 Automatic and Manual Control

On the Siemens panel there are two methods of operating the system. There is a 'manual' setting and an 'auto' setting. The manual setting simply turns the pumps on and off at the operators discretion. The automatic setting utilises the high and low float switches located within the sumps to determine whether the pump should be on or off. Please refer to fig x. for information on how the logic control within the Siemens panel operates.

At the time of writing this document the HMI from Siemens was not installed but within the user interface they have given the named member of staff the ability to set off timers for the high and low switches. At the time of writing this document a staff member of Siemens set this timer to 10 seconds. When the HMI is implemented it would be advisable to increase this to a full minute only on the basis that Siemens have uploaded their timer bypass logic to prevent flooding. Increasing this timer to a minute will minimise the number of times the pump switches off per hour and will prolong the pumps operational lifespan, which will increase productivity and decrease cost.

In the eventuality that all sumps are high, the system would keep running all pumps to avoid overflowing any of the sumps but should give a warning that the system is not operating correctly.

The logic control can be seen below in fig. x for a greater understanding of how the pump control works whilst operating in 'auto' mode.

ATTENTION!

The system should be left in AUTO at all times. If the system or part of the system does need to be run in manual then please observe the following criteria:

- The named member of staff is the **ONLY** person allowed to switch the system to manual.
- The system should only be operated in this way whilst the named member of staff is on site.
- The system should **NEVER** be left in manual overnight.

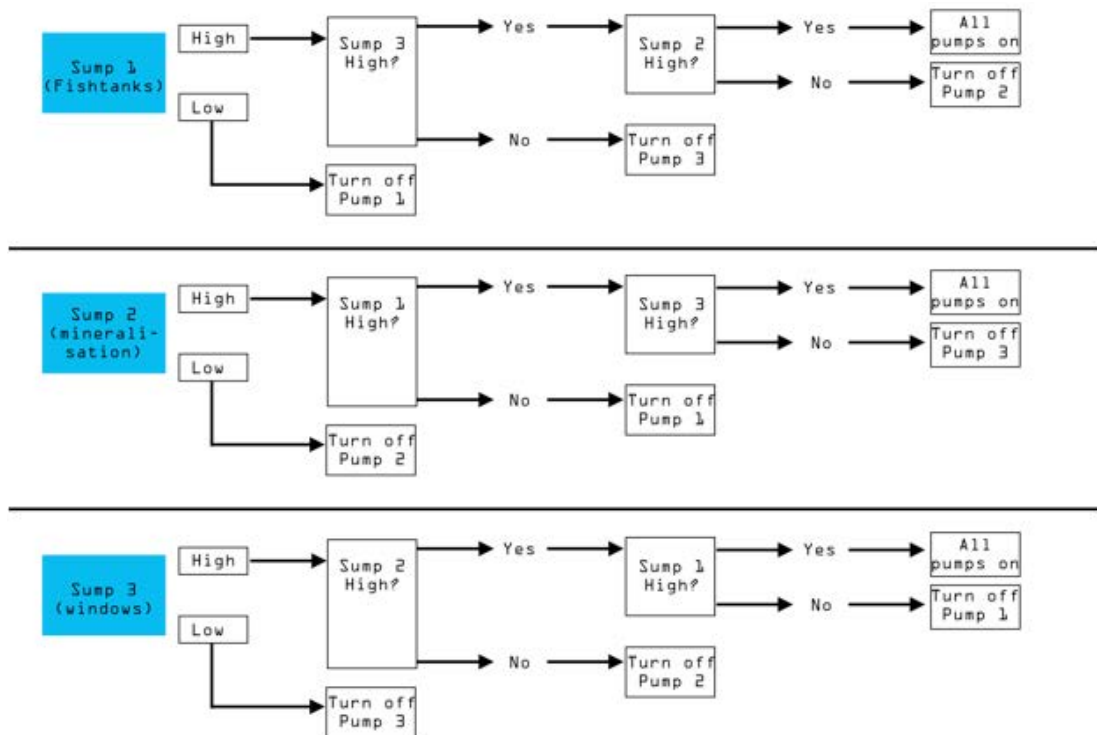


fig 5. pump logic for low and high level switch contained within the three sumps

A.2.3 System Specifications

For full system specification please refer to Appendix C.01

A.2.4 Incidents

ALL incidents in relation to system faults/issues should be recorded on the incident sheet located at the rear of this document. The actions taken to remedy this should also be recorded along with the date and signed by the named member of staff. (See appendix A09)

PART B: LIVING THINGS

B.3.0 Software

B.3.1 Plants

B.3.1.0 System Capacity.

The system has a growing capacity of 900m². The NFT growing system, housed within the polytunnel can support 826m² of growing area. This is achieved using 75mm guttering channels with a 125mm wide lid. Each 2m length of lid holds 10 x 2" net pots and 2 x 3" net pots each at 150mm centres. ALL of the NFT channels are laid at a 1:50 fall to promote optimum water flow.

To ensure the successful maturation of the system, it is recommended that the growing infrastructure within the polytunnel be phased.

With all 3 phases established the system has the capacity to hold 4668 individual crops. Alternatively, the 2m lids can be removed from the NFT channels and the Net Pots replaced with 2m length slabs (See section 3.1.2.0 Growing Media). This will enable seeds to be scattered rather than individually sewn. This technique is recommended for growing Micro herbs, grasses etc. (See section 3.1.4 Propagation)

The Window Growing system is made up of 5 window bays, each accommodating 30 hanging bags. They are made from food grade silicone, each bag measures approximately 300mm(H) x 200mm(W) x 200mm(Dia) and has a holding capacity of approximately 5lt.

The window growing system can potentially provide enough growing capacity for an additional 150 crops (see section 3.1.3 Window System).

B.3.1.0.0 NFT Phase 1 Growing Capacity

Phase 1 is the largest growing platform, supported by a timber frame. There are 4 bays at this level. The two outer bays are 14m in length and are made up of 6 x NFT channels per bay. The two inner bays are 13m in length and each bay is made of 11 x NFT channels. This has a holding capacity for 2796 net pots.

B.3.1.0.1 NFT Phase 2 Growing Capacity

Phase 2 is a succession of suspended growing platforms. The basic plumbing infrastructure for the suspended platforms are in place however, a working knowledge of plumbing, polytunnel construction and carpentry will be required to construct any additional elements.

Phase 2 is the lower of the two suspended platforms. There are 6 x bays consisting of 3 x 13m length NFT channels. This can facilitate an additional 1404 net pots.

B.3.1.0.2 NFT Phase 3 Growing Capacity

Phase 3 is also a succession of suspended platforms. Phase 3 is located above Phase 2 and consists of 6 individual NFT channels at 13m lengths. Each channel can hold 78 net pots, offering an additional 468 net pots.

B.3.1.0.3 System Productivity and Symbiosis.

The aquaponic system is designed to produce an average of approximately 300 crops per week on a ten week grow cycle. The grow cycle is described as the time take from the planting of a seed to the harvesting of the crop. This value will rise to a maximum of 500 crops per week during the hotter months, as the time from seed to harvest could be as short as 6 weeks.

B.3.1.0.3 Crop to Fish Ratio.

It is important that the aquaponic system is ALWAYS full of crops at various stages of growth.

The total weight of fish produce a specific amount of ammonia that is easily estimated and converted into a certain amount of nitrogen that is easily estimated. The approximate level of nitrogen in the water can sustain a certain amount of crops and the system has been designed on these principles.

If the system is ever low on crops, the nitrogen level will increase and the efficiency of the system will decrease. It is the role of the crops to help in the cleaning of the water for the fish. If there aren't enough crops to see that the water is sufficiently cleaned, it will impact on the health and well being of the fish and hence, the health and well being of the system. Please ensure that the NFT and window systems are always full of crops and full of life.

B.3.1.1 NFT.

NFT (Nutrient Film Technique) is soil-less, growing method, used within this aquaponic system as the primary growing method. As with any food growing system, a strong knowledge of horticulture and agriculture is required.

B.3.1.1.0 Growing Medium

NFT uses a direct water flow to distribute nutrients to the root systems of the crops. As there is no soil, a growing medium is used to provide a support for the root structures.

B.3.1.1.0.0 Net Pots

Net pots are used to contain the growing medium, they allow for seedlings to be planted individually, providing flexibility in crop design, rotation and in harvesting. A combination of 2" and 3" net pots have been used within the NFT system allowing for a wider variety of crops to be grown.

Supplier information: (Recommended)

Holland Hydroponics - www.hydroponics.co.uk

Net Pot 2" EXPRESS at 10p each (as of 03/06/2013) or similar.

Net Pot 3" (LARGE HOLE) EXPRESS at 20p each (as of 02/07/2013) or similar.

B.3.1.1.0.1 Mineral Fibre Pads

To ensure the crops are receiving a sufficient supply of nutrient-rich water a small pad of mineral fibre 2 cm (D) x 2 cm (W) x 1 cm (H) should be secured, using a very small amount of food grade silicone to the bottom of every 2" net pot. When the net pot is placed into the NFT lid, the underside of the small pad should touch the bottom of the NFT channel. This small pad should remain saturated at all times, enabling the growing media in the net pots to easily draw up the nutrient-rich water.

With the NFT lid on, the 3" net pots should touch the bottom of the NFT channel without the need of a mineral fibre pad.

B.3.1.1.0.2 Mineral Fibre Mini Cubes

Mineral fibre cubes quickly draw up the nutrients from the NFT channel and retain the sufficient moisture and oxygen mix required by the root systems. They also provide a lightweight, low resistance structure to support fast root growth.

Supplier information: (Recommended)

Holland Hydroponics - www.hydroponics.co.uk

Mini Cubes 100L EXPRESS at £38.90/100L (as of 02/07/2013) or similar.

PLEASE NOTE: when choosing a mineral fibre media, always check that it has NOT been treated with any flame-retardants or other chemicals. HOUSE INSULATION SHOULD NOT BE USED.

B.3.1.1.0.3 Mineral Fibre Slabs

Mineral fibre slabs absorb the nutrient-rich water while still permitting flow. Slabs can be used to grow Grasses, Micro-herbs and other fast growing crops that require minimal space.

Supplier information: (Recommended)

Holland Hydroponics - www.hydroponics.co.uk

Cultilene EXACT 1000mm x 150mm at £3.05/each (as of 02/07/2013) or similar.

PLEASE NOTE: if using a product different to the one recommended, make sure it is suitable for horizontal growing.

B.3.1.1.0.4 Perlite

The small particulate size of Expanded Perlite means it is NOT suitable for use in net pots and should NOT be used within this aquaponics system.

B.3.1.1.1 Crop Suitability

NFT is a lightweight method of aquaponic growing and the design is such to adhere to the strict structural loadings of the roof (Please see independent Structural Surveys). The 75mm guttering provides a shallow growing channel; the shallow nature of the growing channel limits the variety of crops grown to leaf crops, micro-herbs and those with small root systems. Growing crops with large or dense root systems could lead to blockages within the NFT.

Crop selection should therefore be undertaken by someone with a good working knowledge of Horticulture and Agriculture and in particular, crop root systems.

B.3.1.1.2 Seeds

When buying seeds for growing within the aquaponics system, they should be purchased from a reliable source. Local, organic seeds are recommended where possible.

Supplier information: (Recommended)

The Organic Gardening Catalogue - www.organiccatalogue.com

Seeds treated with any form of herbicide, pesticide, fungicide or any other chemical treatments, modifications or additives should NOT be used.

B.3.1.1.3 Plugs

If introducing Plugs to the system that have not been grown on-site (NOT recommended) it is vitally important that these plugs are:

- *Organically grown by a reliable source*
- *Germinated by soil-less growing methods OR*
- *IF grown in soil, the root systems are washed to remove ALL traces of soil.*

Introducing even small amounts of soil to the aquaponics system risks contamination and infestation.

B.3.1.2 Window System.

The window system is a vertical growing platform, which provides additional growing capacity and well as secondary biological and mechanical filtration.

B.3.1.2.0 Growing Medium

The window system acts as both a growing platform and as a second filtration bed. As such, the growing medium is required to suit both uses.

B.3.1.2.0.0 Expanded Clay Balls

Expanded clay balls are lightweight and highly porous, making them an effective growing medium for crops with larger root systems (see 3.1.3.1 Crop Suitability). They also encourage efficient drainage, which is important for a vertical growing system.

Supplier information: (Recommended)

Holland Hydroponics - www.hydroponics.co.uk

Aqua Clay Pebbles 45L at £12.80/45L (as of 02/07/2013) or similar.

PLEASE NOTE: When using Expanded Clay Balls they should be thoroughly washed BEFORE introducing them into the aquaponics system. Rinse the Expanded Clay Balls with clean water until the spent water runs clear. Inadequate washing can cause the water to become cloudy, cause blockages and potentially introduce contaminants into the aquaponics system.

B.3.1.2.1 Crop Suitability

The window bags provide an opportunity to grow a wider variety of crops within the overall system. The depth of the individual grow bags suit crops with large root systems and small root vegetables. There is also the potential to grow climbing varieties as the suspended structure of the window systems provides structural support.

Sufficient drainage is crucial in the vertical window systems. As with the NFT, good crop maintenance is needed to reduce the risk of blockages and floods. To ensure the required maintenance is being achieved and only suitable crops are grown in the window systems, maintenance duties and crop selection should be undertaken by someone with a good working knowledge of Horticulture and Agriculture and in particular, crop root systems.

B.3.1.3 Propagation.

B.3.1.3.0 Mineral Fibre Plugs

Mineral fibre starter plugs are recommended for propagation. Propagation trays should be cut into strips 4 plugs wide and placed within the NFT channels, ensuring each plug receives a steady flow of water.

The process of propagating into mineral fibre plugs is the same as that of propagation into soil plugs and should therefore be carried out by someone with a strong working knowledge of propagation.

Supplier information: (Recommended)

Holland Hydroponics - www.hydroponics.co.uk

Starter Cubes SBS 150 Rockwool (1") Express at £7.15/150 piece tray (as of 02/07/2013) or similar.

In winter months it is recommended that the Polyunnel sides be closed, and the area be heated to achieve the optimum conditions for propagation.

When the seedlings are ready to be planted out, transplant the mineral fibre plug into a net pot and surround with mineral fibre mini cubes (See section 3.1.2.0.2 Mineral Fibre Mini Cubes) or into the window bags and surround with clay balls (See section 3.1.3.0.0 Expanded Clay Balls) as required. The planting out process is the same as that used in traditional soil growing and should be approached in the same way by someone with a strong working knowledge of Horticulture and Agriculture.

B.3.1.3.1 Perlite (NOT Recommended)

Perlite has the potential to collect within the aquaponics system and cause blockages so should not be introduced within the system itself.

IF Perlite is used for propagation, it should:

- *Be kept completely independent of the aquaponics system (not incorporated into the water cycle).*
- *At the planting out stage, the roots should be washed to remove ALL traces of Perlite*
- *Introducing even small amounts of Perlite to the aquaponics system risks blockages and damage.*

B.3.1.4 Harvest.

To ensure the efficient use of the system a strict maintenance and harvesting strategy should be implemented. Someone with a strong working knowledge of horticulture and agriculture must manage this.

Recommended Harvesting Zones can be found on Appendix D05

Regular Risk Assessments should be conducted to ensure the safe and hygienic practice during harvesting.

(Also see APPENDIX C01 Legionella Risk Assessment)

B.3.1.5 Disease & Pest Control

Aquaponics is a closed cycle system, meaning that anything added to the system, will affect ALL living organisms within the system not just the target.

PLEASE NOTE: BEFORE adding anything to the system, ensure it will have NO negative effects of the software of the system.

CONSIDER: small doses may seem harmless but certain substances can accumulate in living organisms and become toxic.

B.3.1.5.0 Poly-cropping

To reduce the risk of disease outbreak and pest infestation, a Poly-cropping technique is recommended. Increasing the diversity of crops within the system will improve the overall resilience and by designing a planting scheme that combines crops with differing physical attributes and disease susceptibilities, disease and pest infestations can be contained and easily treated.

Poly-cropping requires an in-depth knowledge of leaf shape, texture, colour and nutrient requirements as well as flower scent, size and colour and disease resistance and susceptibilities etc. Someone with a good working knowledge of horticulture, agriculture and permaculture should be responsible for the planting and crop designs.

B.3.1.5.1 Ladybirds

Introducing Ladybirds into the growing areas will help to increase the biodiversity of the entire system. They are also a recommended method of natural pest control.

Ladybirds are a natural predator of aphids and will help to reduce the damage caused by infestation.

B.3.1.5.2 Other remedies

DO NOT USE any chemical pesticides, herbicides, fungicides or similar.

ALWAYS CHECK before using any natural pesticide, herbicides, fungicide or similar that they DO NOT contain any substance that could be harmful to the fish, worms, beneficial bacteria or any of the supporting species.

B.3.2 Fish

B.3.2.0 Species (as of 02.07.2013)

355 x 4" - 6" (approx 57g) Common Carp @ £2.10 per fish

85 x 6" (125g - 150g) Red Nile Tilapia @ £1.00 per fish

90 x 8" (175g – 225g) Red Nile Tilapia @ £1.50 per fish

Both the Carp and the Tilapia were sold as Table Fish and certified as Fit for Human Consumption. The Tilapia are certified as Organic.

The Red Nile Tilapia are NOT GMT (Genetically Male Tilapia) meaning they are a mixture of both male and female fish.

B.3.2.1 Suppliers (Recommended)

B.3.2.1.0 Carp Supplier

Aquavision

Upper Hayne Farm, Blackborough, Cullompton, Devon. EX15 2JD

Phone: +44 (0)1823 680888

Email: info@aquavisiononline.com

Contact: Mr Jimmie Hepburn MSc

B.3.2.1.1 Tilapia Supplier

The Fish Company

Scampton House, Scampton, Lincoln, LN1 2SF

Phone: 01255 717706

Email: info@the-fish-company.co.uk

PLEASE NOTE: If using a supplier other than those recommended ALWAYS CHECK that the fish are FIT FOR HUMAN CONSUMPTION. It is recommended that Organic suppliers are used whenever possible.

B.3.2.2 Species Suitability

When introducing a species of fish into the aquaponics system, the following needs to be carefully considered:

- *Do you want an edible species?*
- *What is the temperature of the water in your aquaponics system? Is this compatible with your chosen species?*
- *What does the fish eat?*
- *What conditions does the fish need? (i.e. Does it need a current? Is it a freshwater or saltwater fish?)*
- *Is it a fast growing variety?*
- *What level of expertise is on-site to conduct the fish husbandry?*
- *How hardy is the species?*

The aquaponics system has a minimal current so fish that require a current should NOT be kept unless sufficient flow can be generated within the tank through electrical/mechanical means.

The current system is a freshwater system meaning it is NOT suitable for saltwater species.

PLEASE NOTE: Red Nile Tilapia was chosen as the introductory fish species for its ability to tolerate fluctuating water conditions. Although the aquaponics system is a closed system and the risk to biosecurity is low, it is recommended that once the system has matured, the Tilapia be phased out and only UK native fish species be used.

XX Future Recommendations – Suggested species for cultivation.

Rainbow Trout are a relatively fast growing fish that require lower water temperatures. Food market fish size can be reached in 9 months (30-40cm) but 'pan-sized' fish, generally 280-400 g, are harvested after 12-18 months.

European Perch require around 10 months to reach a harvest size of 100g when kept at the optimum temperature of 22⁰ C but can tolerate lower water temperatures.

ALL re-stockings should be discussed with a recognised Aquaculture professional PRIOR to re-stocking. The restocking process should be co-ordinated, managed and conducted by someone with a good working knowledge of Fish Husbandry and Aquaculture, with specific knowledge of the species used.

B.3.2.3 Stocking Densities

B.3.2.3.0 Tank Densities

The density of fish kept within the system is of key importance for the well being of the fish contained within the aquaponic system. If the fish are kept happy, the system will remain happy. The system wants to promote the welfare of living things as one of its key aims.

The densities of tanks will depend on the size of the fish contained within it. See below:

- Small fish between 0g-100g should be kept at a density of no higher than 20kg/m²
- Medium fish between 100g-250g should be kept at a density of no higher than 25kg/m²
- Large fish between 250g-450g should be kept at a density of no higher than 30kg/m²

B.3.2.3.1 Calculating Density

The density of each tank can be calculated by weighing the fish contained within it. This is achieved by weighing a cross section of the tank population (approximately five fish) and obtaining a mean weight. This weight can then be multiplied by the number of fish within the tank and divided by the water volume.

Example: (100 fish of medium weight in a 750 litre tank)

Five fish are weighed from a medium fish tank.

Results: 120g, 150g, 130g, 130g, 200g

$(120+150+130+130+200) / 5 = 119\text{g}$

$119\text{g} \times 100 \text{ fish} = 11.9\text{kg}$

$11.9 / 0.75 (750\text{L}) = 15.833\text{kg/m}^2$

For a medium tank the maximum density is 25kg/m^2 so the stocking density of this particular fish tank is acceptable.

B.3.2.3.2 Stocking Regulations

The recommendations as stated within the '*RSPCA welfare standards for farmed Atlantic salmon*' document is to not exceed 30kg/m^2 . As stated above the aquaponic system will only consider this maximum density for large adult fish and should always be kept well below this to ensure the well being of the fish within the system. Juvenile and adolescent fish should not exceed 20kg/m^2 and 25kg/m^2 respectively.

B.3.2.4 Habitat Requirements

B.3.2.4.0 Current

The aquaponics system has a minimal current so fish that require a current should NOT be kept unless sufficient flow can be generated within the tank through electrical/mechanical means.

B.3.2.4.1 Tank Substrate

The bottom of each tank is covered with a thin layer of either gravel or pea gravel. A tank substrate is not essential to the system or the basic well being of the fish. However it is recommended. Adding suitable substrates to the bottom of the tank adds interest and should be used to start to replicate the natural habitat of the fish if possible. It also provides a surface in which solid waste can break down and easily be removed from the system.

DO NOT use mud as a tank substrate.

ONLY use aquarium grade tank substrates.

B.3.2.4.2 Extras

Adding larger rocks and stones to the tanks will add interest to the tanks and provide areas to hide and play, further replicating the fishes natural habitats.

PLEASE NOTE: Before introducing anything into the tank, be sure you know what it is made of.

DO NOT ADD anything made of plastic, copper or anything that can be toxic to fish, harmful to humans or alter the water chemistry undesirably.

REMEMBER: this is a closed-loop system. Anything added to the water has the potential to accumulate in the crops and fish.

B.3.2.5 Feeding

B.3.2.5.0 Fish Food Supplier (Recommended)

Organic Tilapia: Fingerling XL30 (priced £29.90/ 25kg bag)
Organic Trout: Emerald Fingerlings SA30 (priced £35.40/ 25kg bag)
Skretting, Wincham, Northwich, Cheshire, CW9 6DF
Email: info.aqua@skretting.com
Phone: 01772 782128
Contact: June Edmondson
Email: june.edmondson@skretting.com

Please check the manufacturer's instructions for storing the fish food.

B.3.2.5.1 Calculating Feeding Requirements

The quantity of feed required per tank will vary with the biomass within each tank. It has been shown previously how to calculate the weight of fish within each tank. This information can then be used to calculate the amount of food that each tank requires. Below are the percentage quantities that are required per tank.

- Small fish (0g-100g) should be fed 3% of their body weight daily
- Medium fish (100g-250g) should be fed 2% of their body weight daily
- Large fish (250g-450g) should be fed 1% of their body weight daily

To follow on from the previous example regarding calculating fish tank densities:

If the weight within a medium tank is 11.9kg the fish within that tank will require 2% of their total weight daily.

To work this out:

$(11.9 / 100) \times 2 = 0.238\text{kg}$ or 238g of food per day.

B.3.2.6 Tank Maintenance

Tank maintenance is important in keeping a healthy and hygienic system and should be carefully managed as part of a System Maintenance and Cleaning Schedule.

To maintain clean and healthy tanks the following is required:

Inside faces of the tanks should be cleaned weekly to remove any Algae build up. This should be done using suitable equipment and by a trained professional. The front glazed element should be cleaned daily as this is the place in which then most algae will grow.

The areas around the tanks should be kept free of all food and debris and tops of the tanks kept generally clean.

Any additional filters used within the tanks should be cleaned daily.

If there appears to be a visible build up of solid fish waste on the tank substrate, this should be siphoned and removed from the system.

DAILY visual checks should be carried out to inspect the tanks for ill, injured or dead fish or debris. Any debris within the tanks should be removed immediately.

DEAD FISH SHOULD BE REMOVED IMMEDIATELY.

The processes involved in aquaponics omit the need for the regular water changes required in traditional aquaculture.

Partial water changes may however be required if:

- *There is an outbreak of disease (bacterial, fungal etc)*
- *Water temperatures reach 25°C*
- *Elevated Ammonia levels*

B.3.2.7 Fish Husbandry

High standards of husbandry must be maintained at all times with the welfare of stock being considered as a priority. Fish must be handled in a considerate and skilled manner. Careful and responsible planning and management must be employed to safeguard welfare during essential procedures and should be done so by someone with a good working knowledge of Fish Husbandry and Aquaculture.

It is highly recommended that the named member of staff on the front of this manual attend a specialised aquaculture course to improve their knowledge of fish husbandry or work with skilled aquaculturists that have access to site on a daily basis to check the health of the fish within the system.

B.3.2.8 Illness, Disease & Death

Daily checks of the tanks should be used as an opportunity to monitor the health and well being of the fish. In the event of a suspected injury or illness, a local Fish Health Professional should be contacted immediately.

B.3.2.8.0 Local Vets contact details.

Please check the Fish Vet Society for local Fish Health Professionals -
<http://www.fishvetsociety.org.uk/>

(RECOMMENDED)

Stuart Becker
B.39 Newton Heath
Middlewich
Cheshire
CW10 9HL
01606 833731
www.willowsvetgroup.co.uk/

B.3.2.8.1 Disposal of Dead Fish

The disposal of Animal by-products is currently managed locally by Salford City Councils Environmental Health Department.

JOAN HOOPER of Salford City Councils Environmental Health Department advises that in the event of fish dying for a reason other than disease (sudden changes in temperature etc.) the fish should be composted on-site.

In the event of fish dying due to disease, Salford City Council Environmental Health Department should be contacted immediately. Animal byproducts are classified as Category 3 Waste and will require specialist collection.

Local Waste Collection Specialists: (RECOMMENDED by Salford City Council's Environmental Health Department)

PDM Ltd
Mancetter Road, Hartshill, Nuneaton, Warwickshire, CV10 0TA
Website: www.pdm-group.co.uk
Phone: Tel: 02476 397571
Email: csc@pdm-group.co.uk

Any dead fish should be kept in an independent freezer, reserved for this purpose until collection to avoid decomposition and smells.

This is subject to change and procedures should be checked regularly with Salford City Council's Environmental Health Department to ensure correct disposal of the Fish.

Please note: The burning of category 3 waste is not permitted and is not a recognised method waste disposal.

B.3.2.9 Harvesting

When harvesting the fish, RSPCA guidance MUST be adhered to.

Fish must be killed humanely without any unnecessary distress or discomfort. Pre-slaughter crowding and handling must be kept to an absolute minimum. Personnel involved in slaughter must be thoroughly trained and competent to carry out the required tasks.

Prior to slaughter, fish must:

- *Only be fasted for the absolute minimum period required to meet food hygiene requirements*
- *Not be fasted for more than 72 hours, unless fasting is beneficial for welfare.*

Crowding and handling prior to slaughter must be kept to an absolute minimum.

Farmed fish must be humanely slaughtered.

The method of slaughter used must rapidly, and without pain and distress, render the fish insensible, until death supervenes.

An efficiently applied percussive blow is the only permitted slaughter method at present. Humane mechanical devices must be used in preference to a manual percussive blow (except for emergency slaughter).

The use of mechanical devices must be monitored to ensure that they are working properly and that they are delivering the stun at the correct location.

One blow must be delivered to the top of the head just behind the eyes, of sufficient force to cause immediate loss of consciousness that lasts until death.

A priest (small hammer) must be available throughout the slaughter process to allow a manual percussive blow to be administered in an emergency.

Bleeding must follow within 10 seconds.

All staff involved with the slaughter process must have received full training to ensure they have the knowledge and skill to perform their task humanely and efficiently.

There must be a named person responsible for fish welfare throughout the slaughter process who has attended a recognised training course in humane slaughter of fish.

Slaughter efficiency must be continuously monitored to ensure that every fish is effectively stunned and does not regain consciousness prior to death.

PRIOR to any fish harvesting; for more information, contact CEFAS, The Fish Health Inspectorate on 01305 206600 and Salford City Council Environmental Health Department on 0161 7944711 and any other relevant governing bodies.

B.3.2.10 Licensing

The Biospheric Foundation is currently registered as and Aquatic Animal Holding with CEFAS (Centre for Environment, Fisheries and Aquaculture Science).

CEFAR REFERENCE: EE070-L-185
LICENCE NUMBER: EW070-M-186R

Please see the Biospheric Foundation for a copy of the certificate.

The Biospheric Project is NOT a registered Fish Farm.

For further information regarding the current registration or information regarding registering as a Fish Farm please contact:

Fish Health Inspectorate, Cefas, Barrack Road, The Nothe, Weymouth, Dorset, DT4 8UB
Phone: 01305 206700
Email fhi@cefas.co.uk

B.3.3 Hens

As with the Fish, High standards of husbandry must be maintained at all times with the welfare of stock being considered as a priority. Hens must be handled in a considerate and skilled manner. Careful and responsible planning and management must be employed to safeguard welfare during essential procedures and should be done so by someone with a good working knowledge of Hen Husbandry and Flock-keeping.

B.3.3.0 Breeds (as of 02.07.2013)

1x Speckledy cost at time of purchase £15.00. Purchased at point of lay.
2x Black Rock cost at time of purchase £15.00. Purchased at point of lay.
2x Blue Ranger cost at time of purchase £15.00. Purchased at point of lay.

B.3.3.1 Supplier

Happy Chicks,
Thornton House Farm, 227 Pilling Lane, Preesall, Poulton Le Fylde, Lancashire FY6 0HH
Email: <http://www.happychicks.co.uk/>
Phone: 01253 814000
Contact – Sarah sarah@happychicks.co.uk

B.3.3.2 Habitat Requirements

The chicken run within the Roof Garden has been designed to meet Free Range standards and should be regularly maintained.

The current design includes graveled areas to provide a well-drained lying area at all times. The perimeter fence allows continuous daytime access to the open run. The majority of the chicken run is lawn area providing the hens with vegetation. There are also a 1m² area filled with sand (childrens play grade) and another 1m² area filled with soil providing the hens with areas to dig and dust bathe in the warmer months. (See section 6.2 Summer Maintenance)

DEFRA suggest a maximum stocking density of 4 birds per m² for free range hens. The designated chicken run is approximately 50m² houses 5 hens. Although there is adequate space, it is NOT recommended that any more hens be introduced to the chicken run. This is due to the rooftop location and drainage capacity of the roof garden.

Due to structural limitations and the welfare of the birds NO MORE than two people should be within the chicken run boundary at any one time.

B.3.3.3 Feeding

A written feeding program is required to ensure that hens are fed a wholesome diet; this should be completed daily and when required. Please see Appendix A07

Fresh food and water should be made readily accessible to hens.

Please ensure the food is:

- *Appropriate to their stage of production*
- *Is fed to them in sufficient quantity to maintain them in good health*
- *Satisfies their nutritional needs*
- *Is provided at all times each day, except when required by the attending veterinary surgeon*
- *Includes a written record of the nutrient content of the feed as declared by the feed compounder*
- *Includes provision of insoluble grit designed for use by poultry (e.g. flint) of appropriate size and quantity.*
- *Includes provision of insoluble grit no less than once weekly.*

Please note:

In-feed antibiotics may only be given for therapeutic reasons under the direction of the attending veterinary surgeon.

All foodstuffs must be safely and hygienically stored, transported and delivered to stock to prevent infestation or contamination or wetting.

Food must not be allowed to remain in a contaminated or stale condition.

5cm of (actual) linear track (10cm single side) or 4cm of circular feeding space must be provided and be accessible for each bird.

Hens must be provided with water:

- That is clean and fresh
- At all times, except when advised by the attending veterinary surgeon.

REMEMBER: Provision must be made for supplying water in freezing conditions.

Drinkers must be:

- *Placed at optimum height for the size and age of the birds*
- *Of an appropriate design.*

Supplier information: (Recommended)

Omlet - www.omlet.co.uk

Organic Omlet Chicken Feed at £9.00/10kg (as of 02/07/2013) or similar.

Organic Omlet Mixed Corn at £9.00/ 10kg (as of 02/07/2013) or similar.

Mixed Chicken Grit - 1.25kg £4.50/ 1.25kg (as of 02/07/2013) or similar.

Hanging Seed Decoration £9.60/ pack of 3 (as of 02/07/2013) or similar.

B.3.3.4 Maintenance

The welfare of laying hens is considered within a framework, elaborated by the Farm Animal Welfare Council, and known as the 'Five Freedoms'. These form a logical basis for the assessment of welfare

within any system, together with the actions necessary to safeguard welfare within the constraints of an efficient livestock industry.

The Five Freedoms are:

- *FREEDOM FROM HUNGER AND THIRST - by ready access to fresh water and a diet to maintain full health and vigour;*
- *FREEDOM FROM DISCOMFORT - by providing an appropriate environment including shelter and a comfortable resting area;*
- *FREEDOM FROM PAIN, INJURY OR DISEASE- by prevention or rapid diagnosis and treatment;*
- *FREEDOM TO EXPRESS NORMAL BEHAVIOUR - by providing sufficient space, proper facilities and company of the animals' own kind;*
- *FREEDOM FROM FEAR AND DISTRESS - by ensuring conditions and treatment to avoid mental suffering.*

In acknowledging these freedoms, those who have care of the hens should practice caring and responsible planning and management and appropriate environmental design (for example, of the husbandry system). They should be skilled, knowledgeable and conscientious in stockmanship.

B.3.3.4.0 Cleaning

Cleaning the coop, feeders and drinkers should be taken as an opportunity to observe the hens and check for behavioural changes or signs of bullying, injury or illness.

B.3.3.4.0.0 Frequency

The hencoop should be cleaned out every 10-14 days, unless there is a clear smell of ammonia, or the bedding appears damp, in which case it should be cleaned immediately.

Damp bedding should be avoided at all costs as many pathogens thrive in it.

A strict and detailed cleaning schedule must be implemented and upheld to ensure the well being of the hens. Please see Appendix A07 for an example. A Health and Safety Assessment is also needed and PPE equipment required. This should be managed by someone with a good working knowledge of flock keeping and should be updated regularly to reflect the needs of the current flock.

B.3.3.4.0.1 Method

The process of cleaning the coop is simple, however it should always be carried out by someone who is has been trained and has a working knowledge of hen keeping.

Remove all muck and bedding from the coop and nest boxes. Use of a Hand Shovel is recommended. Remove the Droppings Board and remove any remaining bedding.

Disinfect the coop with a proprietary poultry disinfectant, paying particular attention to the corners. Remove the perches and the partition in the nest boxes and disinfect.

Rinse all elements with warm water, dry thoroughly and re-assemble.

Layer fresh bedding across the bottom the coop, ensuring a full coverage. (This can act as insulation so you may choose to add more or less depending on the season, but always ensure a full coverage.) Layer fresh bedding (approx 1" thick) into the nest boxes.

The Feeders and Drinkers should also be thoroughly cleaned every 10-14 days. To clean the Feeder and Drinkers:

- Remove all remaining contents and disassemble if possible.
- Wash the INSIDE and OUTSIDE with a mixture of warm water, a mild first aid disinfectant and a small amount of washing up liquid. Use of a scrubbing brush is recommended.
- Rinse thoroughly with clean water to remove all traces of cleaning solution.
- Dry thoroughly and reassemble before refilling.

In addition:

- *Feeders should be wiped out with a damp cloth every other day and the undersides washed with an antibacterial wash.*
- *Drinkers should be cleaned everyday, as possible contaminants aren't always visible.*
- *The insides should be scrubbed thoroughly to remove an traces of algae, especially in the warmer months*
- *The underside should be washed with an antibacterial wash.*

DO NOT use any cleaning products that contain PHENOL, as this is poisonous to poultry.
DO NOT fill drinkers with water from water butts as it may have been fouled by other animals or contain poisonous algae or other disease.

B.3.3.4.0.2 Bedding Suppliers

Supplier information: (Recommended)

Happy Chicks - www.happychicks.co.uk

25kg Dust Extracted Bedding / Shavings at £7.00/25kg (as of 02/07/2013) or similar.

AVOID hay or long shredded paper as it can tangle around the bird's legs and often cakes with bird droppings and festers, encouraging toxic mould spores. Finely chopped bark can contain spores and should also be avoided.

B.3.3.4.1 Wing clipping (conducted by professional)

Clipping the Hens wing is essential in preventing the hens attempting to fly over the perimeter fencing. This should be done annually, and always by a professional.

B.3.3.4.2 Winter Requirements

During the winter months, ensure there is enough shelter for the birds.

The Chicken Coop, Timber fence and Bee Hives within the roof garden should be secured to the fence and with Anchor bolts if required to reduce the risk of blowing over in high winds.

This work must be completed by an experienced professional.

(See section 6.3 Winter Maintenance)

B.3.3.4.3 Summer Requirements

During the summer months, ensure there is enough shelter for the birds.

Ensure there are enough provisions for the birds to access clean water. It is RECOMMENDED that a small, lightweight birdbath be provided.

During periods of hot dry weather, the turf area within the Chicken run may need watering. During one-off hot days 3-4 watering cans of water should be evenly distributed over the turf. During ongoing periods of hot dry weather it may be more labour-efficient to use a sprinkler system for 1 hour, 2 times a day.

(See section 6.2 Summer Maintenance)

B.3.3.4.4 Month-by-month care plan

DECEMBER & JANUARY - There are likely to be very few eggs from the older birds at this time of year. The biggest danger is the possibility of frozen water. Put Apple Cider Vinegar in all the drinkers, this can alter the freezing temp of water by about 1c. MAKE SURE there is always a spare drinker for this time of year. Keep it inside ready to use should the usual one become frozen. This will ensure the hens always have access to drinking water and will reduce the risk of breaking the existing drinker by trying to remove the frozen ice. INSPECT the coop regularly to ensure it is still withstanding the weather conditions, in particular, the wind loads. Strengthen and reinforce the coop if necessary. (SEE OCTOBER)

FEBRUARY – This is when most hens come back into lay. During frosty weather, check for and collect the eggs in the morning and evening. Frozen eggs can crack due to the extreme temperatures. The first eggs of the year have a tougher shell, but a stronger yolk and are edible.

MARCH – The grass in the chicken run should start to grow. With the ground naturally recovering, this is the best time to worm the hens ready for the new year. Use Flubenvet 5% pre mixed (recommended by and available from HAPPY CHICKS) by replacing the normal layers with the Flubenvet layers.

APRIL – At this time of year you are likely to encounter an angry bird in the nest box. TAKE EXTRA CAUTION when collecting eggs, Broody hens can growl and peck. This is perfectly normal but may last for a number of weeks. When collecting the eggs, try putting some dummy eggs in the Laying Box.

MAY – The Hens should be dusted every month to prevent lice or mites. If this has not been done, it is very important that it is done during this month and from now on through the summer to keep the hens bug free. PLEASE ENSURE there is ample shade for the hens during the next few months

JUNE & JULY- Long summer nights means the hens won't go to bed till late. Luckily, with the roof-top location of the chicken run, predators shouldn't be a problem, meaning there is no need to lock to coop, just ensure that the gate is closed. Hens normally go to bed half a hour before dark so in summer months it can be 11pm and winter months it's 4pm. If, for any reason there is a need to shut the hens in the coop, try giving them a handful of corn when you want them to go in and they should go in straight away. PLEASE REMEMBER if you are locking the hens in the coop that someone is available to unlock the coop early in the morning, allowing the hens out into their run. Leaving the hens shut in the coop, especially during the warmer months, can lead to the birds getting stressed and harming themselves and each other.

AUGUST - Use this month to get up to date with any healthcare issues. Add plenty of crushed fresh garlic or powdered garlic to the water to keep the flies away during the hot weather.

SEPTEMBER – Rotate the coop throughout the year to ensure a steady supply of grass to the roof-garden. Take this opportunity to 'rest' an area of run to help preserve an area for winter. If the run is becoming waterlogged, consider replacing the sand and soil areas with a thin covering of untreated bark but get this approved by a structural engineer before making ANY changes as the roof loadings have been carefully considered and approved by BDP.

OCTOBER – Get the coop ready for winter. With the bad weather approaching, check the coop to ensure there are no damp spots or draft areas. Check the roof, and any pop holes to make sure fitting and fixtures are secure. The Roof-top location means there are higher wind loads to consider. Secure the coop to the scaffolding fence to restrict movement and prevent the coop from over-turning.

NOVEMBER – During this time of year hens drop their feathers and re-feather - This is called the 'moult'. The egg supply may decrease and the birds may look scruffy and 'bare bottomed' for a while. The hens will soon re-feather and regular laying will continue. During this time it is recommended that the hens are given extra vitamins. (Poultry Spice is recommended by and available from HAPPY CHICKS)

B.3.3.5 Illness & Disease

Daily checks of the Hens should be used as an opportunity to monitor the health and well being of the birds. In the event of a suspected injury or illness, a local vet should be contacted immediately.

3.3.5.0 Local Vets contact details.

Ashleigh Veterinary Center
221 Upper Chorlton Road
Manchester
M16 0DE
0161 881 6868
contact@ashleighvets.co.uk

OR

Avian Veterinary Services
At Gauntlet Birds of Prey Center
Manchester Road
Knutsford

Cheshire
WA16 0SX
24 hr phone line: 01565 654131
info@avianveterinaryservices.co.uk

B.3.3.5.0 Disposal of Dead Birds

Fallen stock can be any bird or animal that has:

- *Died of natural causes or disease on the farm*
- *Been killed on the farm for reasons other than human consumption*

Approved means and places for the disposal of fallen stock MUST be used. The National Fallen Stock Company (NFSCo) can help with the disposal of fallen stock and advise on the disease prevention rules, as part of the National Fallen Stock Scheme (NFSS).

If you suspect that a bird or animal has died of a notifiable disease, you must tell your local Animal Health Office (AHO) immediately.

For more information see - www.gov.uk/fallen-stock

B.3.3.5.0.0 Local AHVLA and NFSCo Contact Details

NFSCo Helpline: 0845 054 8888

Local AHVLA Field Office - Preston
Barton Hall Garstang Road Barton Preston Lancs, PR3 5HE
Telephone: 01772 861144
Fax: 01772 861798
Nightline: 01772 861144
Email: EnglandNorth@ahvla.gsi.gov.uk

B.3.3.6 Eggs

B.3.3.6.0 Sale of Eggs

The sale of Eggs is governed by the AHVLA.

If eggs are to be sold to a catering establishment (shop, kitchen, restaurant, pub etc.) the Biospheric Foundation must be registered as an Authorised Producer and Packer by the AHVLA and salmonella stamped.

B.3.3.6.1 Utilising Eggshells

The shells of the eggs produced by the hens can be used to help regulate the chemical balance of the water within the aquaponic system by acting as a pH buffer. (See section 4.3 Water pH)

Place a handful of crushed eggshell into a fine net bag (a pair ladies tights work well) fasten the bag and secure it to the top of the fish tank, ensuring the crushed eggshell is fully submerged. Replace the eggshell every 6-8 weeks or as required.

B.3.3.7 Legislation & Guidance

DEFRA does not require flocks under 50 birds to be registered on the GB Poultry Register, however it is recommended that all flocks are registered.

The hens are not registered as of 02.07.2013

B.3.4 Bees

Responsibility for the management of the Apiary should lie with a registered BBKA Bee Keeper (who also holds a valid BBKA General Bee Husbandry certificate) and the Biospheric Project Manager. Someone with a valid BBKA General Bee Husbandry Certificate should carry out all bee-keeping duties.

A Health and Safety Assessment is also needed and PPE required.

B.3.4.0 Supplier

Fozz – Bees

Mr Christopher Forster

35, Biddall Drive, Baguley, Wythenshawe, Manchester, M23 1PE

Phone: 07903111189 OR 07903111189

Email: fozzys1@hotmail.com

B.3.4.1 The Hive

B.3.4.1.0 Type of Hive

1 x Cedar hive with stainless steel inners.

1 x Nuc of Bees supplied.

1 x Double hive stand.

B.3.4.1.1 Location of the Hive

Any relocation of the Beehive should FIRST be discussed with an experienced, BBKA registered, General Bee Husbandry certified Beekeeper.

PLEASE CONSIDER the possible impact on local residents before relocating the hive.

B.3.4.2 Local Beekeeping Association

Manchester & District Beekeeping Association

Dower House, Heaton Park, M25 2SW

www.mdbka.com

B.3.4.2.0 Regional Bee Inspector

Ian Molyneux

Email: ian.molyneux@fera.gsi.gov.uk

Phone: 07815 872 604

B.3.4.2.1 BBKA Helpline

British Beekeeping Association
Phone: 024 7669 6679
www.bbka.org.uk

B.3.4.3 NBU & Fera Helplines

National Bee Unit
Phone: 01904 462 510
Fera Bee Health Policy Helpline
Phone: 01904 465 636

B.3.5 Aquaponic Water Filtration

Sufficient and effective filtration is vital to the health and productivity of the aquaponics system. It must be regularly maintained by someone with a good working knowledge of aquaponics, aquaculture and vermiculture.

The filtration unit within this aquaponic system uses an experimental approach, which has been carefully designed to provide both biological and mechanical filtration.

B.3.5.0 Filtration, Mineralisation & Ionisation Bank (FMI Bank)

The Filtration, Mineralisation & Ionisation (FMI bank) is a vertical system that provides mechanical filtration, through the collection and treatment of solid fish waste. As the water circulates through the FMI bank, bacteria convert the ammonia rich water into a nitrate rich solution.

The FMI bank consists of x14 vertical rows of x7 individual filtration beds.

Each filtration bed is has a 15lt capacity and should be filled with 10lt - 12lt of Media.

Each vertical row has its own water feed. The water is gravity-fed through the suspended filtration beds and collected in a communal sump built within the bottom of the FMI bank.

B.3.5.0.0 Media

The media used within the filtrations beds is the key to efficient water filtration.

It is recommended that Expanded Clay Balls be used only.

Supplier information: (Recommended)

Silvaperl - www.william-sinclair.co.uk

Albion Works, Ropery Road, Gainsborough, Lincolnshire DN21 2QB

Phone: 01427 610160

Email: silvaperl@william-sinclair.co.uk

Expanded Clay 8 - 12mm at £6.50/50L (as of 02/07/2013) or similar.

Expanded Clay 4 - 10mm at £5.92/50L (as of 02/07/2013) or similar.

Expanded Clay 4 - 8mm at £7.15/50L (as of 02/07/2013) or similar.

PLEASE NOTE: When using Expanded Clay Balls they should be thoroughly washed BEFORE introducing them into the aquaponics system. Rinse the Expanded Clay Balls with clean water until the spent water runs clear. Inadequate washing can cause the water to become cloudy, cause blockages and potentially introduce contaminants into the aquaponics system.

B.3.5.0.1 Biological filtration

Biological filtration is used to remove ammonia from the water by converting it into Nitrate.

B.3.5.0.1.0 Bacteria

Naturally occurring nitrifying bacteria colonise the media within the filtration beds. As the water circulates through the filtration beds, the bacteria convert the harmful ammonia within the water into nitrates, which are then utilised by the crops.

Nitrosomonas: are the bacteria that convert ammonia into nitrites,

Nitrobacter: are the bacteria that convert nitrites into nitrates.

See section 3.9.1 Temperature Range for Bacteria

The bacteria require a moist highly aerated environment and a steady supply of ammonia to thrive and efficiently filter the water. If the FMI bank is allowed to dry, flood or the source of ammonia stop, the population of beneficial bacteria will start to fall rapidly. This can cause a decrease in the efficiency of the biological filtration and could result in having to re-cycle the system. (See section 4.1 Cycling the system)

Insufficient biological filtration will cause ammonia levels to increase, which will cause fish to become stressed, ill and possibly die. Regular ammonia checks will give a good indication of the health of the FMI bank. (See section XXXXXX)

B.3.5.0.2 Mechanical filtration

The use of media within the FMI bank allows the solid waste from the fish tanks to be removed from the water as it passes through the vertical filtration beds.

Grading the particulate size of the media increases the efficiency of the filtration.

8mm – 12mm Expanded Clay Balls for the top 2 rows.

4mm – 10mm Expanded Clay Balls for the middle 3 rows.

4mm – 8mm Expanded Clay Balls for the bottom 2 rows.

B.3.6 Worms

The addition of worms to the Filtration and Mineralisation Bank is an experimental approach to breaking down the solid waste produced by fish, to reduce the maintenance of the aquaponics system and increase the productivity. *XX

B.3.6.0. Worm Species

Species of worms introduced to the system are Eisenia Fetida (also spelled 'foetida') (RECOMMENDED) OR Eisenia Hortensis. Eisenia Fetida can often be referred to as: Red Worm, Red Wiggler, Brandling Worm, Manure Worm or Tiger Worm.

When the Filtration and Mineralisation bank is performing correctly the worms should self regulate, meaning there is no need to add or remove worms from the filtration beds. A good visual indicator the worm populations are self-regulating is the presence of Worm Eggs and Juvenile worms.

Red worm eggs look like tiny straw-coloured lemons. Young worms look like very small versions of the adults but have less red pigment.

B.3.6.0.0 Required Conditions

The worms can thrive in environments with 80% - 90% moisture content, however high levels of oxygen are also required. In the event that a filtration bed has become blocked or flooded, it is likely that the worms will not survive. Further worms should be introduced to the filtration bed once the blockage has been rectified and sufficient drainage has commenced to ensure effectiveness.

PLEASE NOTE: Regular light is harmful to the worms but red light is not.

B.3.6.0.1 pH Levels

The Eisenia Fetida species of worm has a pH tolerance of between 4-9. However the optimum pH is between 6-7 and this should be maintained. (See section 4.3 Water pH)

Adding crushed eggshells to the filtration beds can be used to neutralise the pH levels and can help stimulate worm reproduction.

*XX Future Recommendation – After a trial period of 7 days with the worms within the Filtration beds, migration of the worms was minimal. It is however advised that this is checked regularly. If migration increases it is recommended that individual mesh screens be installed on each bed. Remember that the gauze size should be small enough to prohibit worms moving through it yet large enough to allow solid waste to pass through it.

*XX If the inclusion of worms to the Filtration and Mineralisation bank becomes problematic or proves to be ineffective it is recommended that the TOP row of filtration beds be emptied and the media be replaced with 2" thick slabs of dense sponge, these sponges are to be removed and washed and replaced once a day. The second row should also be modified if required.

B.3.7 Water Chemistry

The pH level within the aquaponics system will change over time depending on how it is running and how well it is being maintained. The system will not settle on a particular pH and stay there. For this reason pH levels should be checked and recorded daily. (See section 1.1 Daily tasks)

B.3.7.0 Ideal pH Range

The pH of the aquaponic system should be maintained between 6.8 and 7.2.
(See section 4.3.3 pH Buffer)

B.3.7.1 Actions if pH is too high

An alkaline system indicates an unhealthy system and should be dealt with immediately. It represents an increasing population of anaerobic bacteria, which is bad for the health of the system. This could indicate that the system is too dirty or the filtration beds are flooded and not receiving enough oxygen. The nitrification process will cause the system to become more acidic over time so a deep clean will help remove debris and dirt; the places in which anaerobic bacteria thrive.

B.3.7.2 Actions if pH is too low

It is normal for the system to get more acidic over time. If the pH is allowed to fall below 7.0 the nitrification process will start to slow down. The nitrification process will slow dramatically by 6.5 and lower. It is important that this does not happen.

The pH of the system can be increased (made more Alkaline) by adding Calcium Hydroxide [$\text{Ca}(\text{OH})_2$] "Hydrated Lime" (RECOMMENDED) or Potassium Hydroxide [KOH] "Caustic Potash".

In both cases be very careful. Add a small amount of the powder to a bucket of water. Then pour it into the system slowly over the period of a day. Remember, these substances are very Alkaline so should be added gradually and the rise in pH be monitored closely.

PLEASE NOTE: Calcium Hydroxide is reasonably safe however Potassium Hydroxide is not. BOTH however should be handled with care.

Additional Reading: <http://www.aquaponic.com.au/Water%20Chemistry.pdf>

B.3.7.3 pH Buffer (RECOMMENDED)

To prevent the pH levels becoming too low, it is recommended that a pH buffer be introduced to the fish tanks. Place a handful of crushed eggshell into a fine net bag (a pair ladies tights work well) fasten the bag and secure it to the top of the fish tank, ensuring the crushed eggshell is fully submerged. Replace the eggshell every 6-8 weeks or as required. Bags should be added or removed as necessary.

B.3.8 Flow Rates

The aquaponic system aims to give each tank a water change per hour to maintain water quality. The combined volume of the fish tanks is approximately 9,000L. As a result the system aims to move 9,000L/hr.

B.3.9 Water Temperature

B.3.9.0 Temperature Range for Fish

As with other water chemistry parameters, fish do not like sudden changes in water temperature. Fish can usually adapt to slow changes in water temperature but if this change is greater than 1.5°C - 2°C in less than 24 hours, most fish are likely to suffer in some way.

The temperature range required by the Red Nile Tilapia is between 24°C - 32°C.

The temperature range tolerated by the Common Carp is 3°C - 32°C. Temperatures between 23°C - 30°C are optimum for growth.

It is RECOMMENDED that the water temperature within this system is maintained within the range of 18°C - 23°C for the current fish species.

* XX Future Recommendations – The water temperature within the system should be maintained within the range of 16°C - 20°C, temperatures suitable for the cultivation of European Perch and Rainbow Trout and ideal for Nitrifying bacteria and plant growth while remaining below the temperatures required for Legionella activity.

B.3.9.1 Temperature Range for Bacteria

Nitrifying bacteria required for the ammonia to nitrate conversion have a preferred temperature range of around 20°C.

Water temperatures should be kept below 25°C for Legionella control. (See Appendix B01 Legionella Risk Assessment)

B.3.9.2 Temperature Range for Plants

14°C - 22°C is the recommended water temperature range for optimum plant growth.

B.4.0 Annual Deep Clean

It is crucial that every year the system is fully shut down and given a full system deep clean. It is recommended that this happen during the coldest months of the year when production of the system is very low. The following section will outline the tasks that need to be completed during this shutdown and also explain how to restart the system after this.

The system will be off for several weeks during this time so no living thing can be left within the system or it will more than likely die. It is recommended that in the build up to this annual deep clean that all fish and all plants be sold to allow full access to all components of the system.

The below will outline the tasks that need to be completed during this time. Due to this being a deep clean and no living things being in the system the solutions of the approved cleaning products can be slightly stronger to provide a greater cleaning power. The aid of a steam cleaner for hard surfaces would also make this task easier as well as minimising the use of chemicals.

ATTENTION!

Failure to conduct this yearly deep clean will lead to the eventual failure of the system due to a lack of proper care.

B.4.1 Annual Deep Clean Tasks in Detail

- ***Fully drain the system.***
 - For the annual deep clean to be completed the system needs to be full drained. This includes the draining off all sumps and all fish tanks, allowing the water to fall out of the system for 24 hours. This will ensure most of the water has fallen out of pipe work, window bags, NFT etc.
- ***Deep clean of fish tanks.***
 - All fish tanks will require an intense clean to minimise contamination from one year to the next. With the fish tanks drained the tank substrate should be removed and the last amounts of water be collected by a wet vacuum. Every corner should be scrubbed clean to ensure they are as clean as humanly possible. During this time the tank substrate can also be cleaned and sterilised.
- ***Deep clean ALL pipe work.***
 - Every single section of piping must be dismantled and thoroughly cleaned inside and out. The inside of pipe work will rarely see the light of day and as a result should be cleaned and sterilised and then reconnected. It is important that pipe sections be cleaned in such a manner whereas the location of each component can be easily remembered, allowing easy reconnection and an easy rebuild.
- ***Yearly pump service (by professional).***

- The pumps get deep cleaned daily so the need to clean them is very low during the annual deep clean. However, whilst the system is off for a significant period of time the pumps should be taken to a specialist to service them. This will give the pumps a clean bill of health for the next year of operation and should see them last many, many years

- ***Deep Clean of Filtration unit.***

- Every single filtration pod should be removed from the filtration unit and given a deep clean. The unit itself should also be cleaned during this time including the metal hangers, the sump the timber, the plastic sheeting etc. The media however should be left out ready to be cleaned.

- ***Deep clean of window system.***

- The deep clean of the window system sees all media removed from the bags and all bags removed from the lintels for inspections. This is the time when broken bags can easily be fixed or replaced. At this point every bag should be cleaned inside and out with special focus paid to the internal corners where dirt collects. The bags can then be re-hung but the media left out ready to be washed with the rest of the media. The deep clean of the window system includes the full cleaning of all pipe work, gutters and sump.

- ***Deep cleaning of ALL media.***

- Although the media is never to be cleaned throughout the year, the annual deep clean sees the full volume of media sterilised. The tiny pores within the media balls will gradually fill with dead bacteria and bacterial mucus. The filling of these areas reduces the surface area of the media ball drastically over the course of the year. The bacterial population will gradually decline and become less efficient. To ensure the longevity of the system the media balls should be sterilised in a weak bleach solution to kill the bacterial population.

Once cleaned the media can be added back to the system. Due to the removal of the bacterial colony from the system the filtration unit will need to be cycled before any fish can be added to the system. If the bacterial population is extremely low as it will be after cleaning and fish are added, there will be no bacteria to deal with the levels of ammonia coming from the fish tanks and as a result, the fish will inevitably die.

- ***Deep clean of NFT system***

- The NFT system will need to be fully dismantled and deep cleaned. The joints are the places where most dirt can build up and as result must be taken apart to clean these areas properly. Although each section of guttering is supposed to be 2m as delivered by the manufacturer, they are in fact not uniform lengths. As a result the location of each and every NFT channel must be noted before the section is removed and cleaned, allowing for straight forward rebuild.

- ***Deep clean of polytunnel***

- The polytunnel does require much maintenance but the inside and outside of the polythene should be cleaned and inspected for tears or wear. These can easily be fixed during this time. The steel and timber sections that create the structure should be inspected for damage or wear and should be repaired or replaced if needed.

- ***General tidy up and other maintenance***

- During this time the system will be off for several weeks, providing access to areas that have been unreachable for some time. During this deep clean timber sections can be replaced, areas like the structure of the filtration unit or aquaculture lab enclosure can be repainted, areas that are damaged due to water can be replaced and areas that are dirty can simply be cleaned. During this annual shut down is the perfect time to complete all the small jobs that have built up over the year or work that could not have been started due to visitors or events. The building should be shut down to visitors and as many hands brought on to help out with the work. After the annual deep clean is completed the system will be ready to accept its first crop of the year and will look impressive to the first visitors.

- ***System refill***

- Once clean and dry, the system should be fully refilled. Although this will take some time it will provide the system with the best chance of success of the next agricultural year.

B.4.2 Cycling the system

Upon completing all the above tasks the system will need to be restarted from fresh. This includes a full system refill and a restart of the bacterial population referred to as 'cycling'. There are two options for the cycling of an aquaponics system. One option includes fish and referred to as 'cycling with fish' and the other does not use fish and is referred to as 'fishless cycling'. From our experience it is far more humane to cycle the system without fish. If fish are used to increase the population of bacteria through the production of ammonia, the ammonia levels can become critical and would kill the fish population. In such a large system 50% water changes would be almost impossible to achieve to save the fish if ammonia levels became too high.

The information used when initially cycling the aquaponic system can be found here:

<http://theaquaponicsource.com/2010/11/01/starting-your-aquaponics-system-using-fishless-cycling/>

The information on this website is from the renowned work by Sylvia Bernstein, which can also be found in the book entitled *'Aquaponic Gardening: A Step by Step Guide to Growing Fish and Vegetables Together'*.

B.5.0 Polytunnel Maintenance.

B.5.1 Design and Manufacturer details

Supplier: First Tunnels Ltd- www.firsttunnels.co.uk

Order Placed: 29th March 2013

Order Number: FT27361

Purchase Order No: 6877

Specification:

Width: 24ft

Length: 54ft

Additional: Thermal Anti Fog Cover

Hot Spot Tape Kit

Twin Support Brace Kit

Base Plate Kit

Timber Base Rail Kit

Timber Side Vent - Left & Right

Vent Screen – Left & Right

Sliding - Double Door - Front End& Rear End

B.5.2 Summer Maintenance

The maintenance in summer is rather low but every so often the polythene should be cleaned to remove dust and keep light levels within the polytunnel as high as can be.

B.5.3 Winter Maintenance

The maintenance in winter is rather low but every so often the polythene should be cleaned to remove dust and dirt and keep light levels within the polytunnel as high as can be. During winter water may collect on the inside of the polytunnel and promote the growth of mildew. The inside of the tunnel should also be cleaned every so often to again keep light levels high within the polytunnel.

B.6.0 Roof Garden Maintenance

B.6.1 Summer Maintenance

During periods of hot dry weather, the turf area within the Chicken run may need watering. During one-off hot days 3-4 watering cans of water should be evenly distributed over the turf. During ongoing periods of hot dry weather it may be more labour-efficient to use a sprinkler system for 1 hour, 2 times a day.

If the lawn area within the chicken run does not recover, the area should be cleared and new lawn laid as per the original design.

Pathways should be swept once a day, in the morning and when required to keep walkways clear of gravel etc.

*XX Future Recommendation: lay non-slip floor covering to all walkways (requires dry conditions)

PLEASE NOTE: If any roof covering is to be changed it MUST be signed off by a Qualified Structural Engineer. If any of the roof coverings are to be replaced, they MUST match the details, depths and areas of the original design.

B.6.2 Winter Maintenance

Following periods of heavy rainfall large puddles should be swept out to evenly distribute the water and encourage drying. Special effort should be made to direct water down the drainage pipe to avoid standing water.

*XX Future Recommendation: Additional drains should be implemented on the roof to encourage drainage.

Pathways should be swept once a day, in the morning and when required to keep walkways clear of gravel, leaves etc.

The Chicken Coop, Timber fence and Bee Hives within the roof garden should be secured to the fence and with Anchor bolts if required to reduce the risk of blowing over in high winds. An experienced professional must complete this work.

PART C: FUTURE RECOMMENDATIONS AND APPENDICES

C.7.0 Future Recommendations

C.7.1 Description

As the aquaponic system within Irwell House is highly experimental, it will in the future need changing and adapting in order to improve year on year. The below recommendations are to help to ensure the systems success and longevity of the aquaponic system itself

C.7.2 Points of Recommendation

- *No Entry/Staff Only signage on the aquaculture lab (Legionella)*
- *Current design is running at around 60-70% of its potential growing capacity. The infrastructure is in place to increase the growing capacity within the Polytunnel and the parts/equipment required was ordered. Include drawings?*
- *Food Grade Hydrogen Peroxide for cleaning.*
- *Treat Bee Hive*
- *Winter modifications to Roof Garden – PLAN*
- *Future Recommendation – After a trial period of 7 days the worms within the Filtration beds, migration of the worms was minimal. It is however advised that this is checked regularly. If migration increases it is recommended that individual mesh screens be installed on each bed. Remember that the gauze size should be small enough to prohibit worms moving through it yet large enough to allow solid waste to pass through it.*
- *Future Recommendations - Rainbow Trout Food market fish size can be reached in 9 months (30-40cm) but 'pan-sized' fish, generally 280-400 g, are harvested after 12-18 months. European Perch require around 10 months to reach a harvest size of 100g at optimum temperature. (22)*
- *Future Recommendations - Lay non-slip floor covering to all walkways (requires dry conditions)*

C.8.0 Appendices

A – Sign-off Sheets, Reports & Logs

- A01. Daily Maintenance Sign-off Sheets
- A02. Weekly Maintenance Sign-off Sheet
- A03. Monthly Maintenance Sign-off Sheet
- A04. Quarterly Maintenance Sign-off Sheet
- A05. Annual Maintenance Sign-off Sheet
- A06. Additional Maintenance Sign-off Sheet
- A07. Poultry Maintenance Sign-off Sheet
- A08. Aquatic Feeding Sign-off Sheet
- A09. Incident Report Log
- A10. Repairs Report Log
- A11. Alterations Log
- A12. System Filling Log

B – Legionella

- B01. Risk Assessment: The control of Legionella in Technical Food Systems

Appendix A01. Daily Maintenance Sign-off Sheets

Morning Task Sheet - Aquaponics System

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
SYSTEM ON:			
<i>Morning Walk Around</i>			
<i>Fish tanks receiving water</i>			
<i>Air stones are operational</i>			
<i>Tank outflow pipes are connected and vertical.</i>			
<i>Window splash check</i>			
SYSTEM OFF:			
<i>All three pumps turned off</i>			
<i>Uncouple all three pumps</i>			
<i>Inspect all pumps for blockages.</i>			
<i>Remove any blockages.</i>			
<i>Deep clean inside pumps.</i>			
<i>Clean pump filters</i>			
<i>Inspection and debris removal from sumps</i>			
<i>Reconnect pipe work to pumps.</i>			
<i>Test Pumps for spraying</i>			
<i>Uncouple all three UV filters.</i>			
<i>Remove all three UV filters from wall.</i>			
<i>Disassemble all three UV filters.</i>			
<i>Full clean of the inside of all three UV filters.</i>			
<i>Reassemble all three UV filters</i>			
<i>Fit UV filter back to wall</i>			
<i>Pressure test all UV filters</i>			
<i>Blockages in roof manifolds</i>			
<i>Clean 4mm black hose</i>			
<i>NFT channels free from obstruction.</i>			
<i>NFT debris baskets are clear of obstruction.</i>			
<i>Check window bungs</i>			
<i>Clean return gutters on window system.</i>			
<i>Ensure window debris collectors are clear.</i>			
SYSTEM ON:			
<i>Bilge pump operating correctly</i>			
<i>pH baths flowing.</i>			
<i>Tank heaters operational</i>			
<i>Clean two filter pumps</i>			
<i>Remove airlocks at every outlet valve.</i>			
<i>Inspect all valves for blockages.</i>			
<i>Remove valve blockages if necessary.</i>			
<i>Inspect filtration pods for blockages.</i>			
<i>Remove filtration blockages if necessary.</i>			
<i>Fill the System (if required)</i>			
<i>Final walk around</i>			

Appendix A02. Weekly Maintenance Sign-off Sheet

Weekly Task Sheet - Aquaponics System

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
<i>Chemical water tests.</i>			
<i>Inspect sumps for wear or damage.</i>			
<i>Clean sumps, dry, repair if required and refill</i>			
<i>Clean window bags inside and out</i>			
<i>Repair any broken joints on window bags</i>			
<i>Clean NFT channels</i>			
<i>Clean every side of fish tanks</i>			

Chemical Tests:	Ammonia	Nitrite	Nitrate
Reading:			

Weekly Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
<i>Clean Coop & check for damage or infestation</i>			
<i>Wash Feeders and drinkers thoroughly</i>			
<i>Check for signs of rats and other</i>			
<i>Check hens for lice and mites</i>			

Weekly Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
N/A			

Appendix A03. Monthly Maintenance Sign-off Sheet

Monthly Task Sheet - Aquaponics System

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
<i>Change first set of 10mm clear hose</i>			
<i>Place outlet bungs into the new 10mm clear hose.</i>			
<i>Clean and dry first set of 10mm clear hose</i>			
<i>Change 4mm black hose and manifolds on roof</i>			
<i>Clean and dry 4mm black hose and manifolds</i>			
<i>Disassemble all push fit components</i>			
<i>Reassemble push fit components</i>			
<i>ALL joints to be inspected in detail</i>			

Monthly Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
<i>(See Section 3.3.4.4 Month-by-month care plan)</i>			

Monthly Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
N/A			

Monthly Task Sheet - Legionella

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
Ensure UV filters are operational			

Appendix A04. Quarterly Maintenance Sign-off Sheet

Quarterly Task Sheet - Aquaponics System

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
<i>Deep clean of ALL piping.</i>			
<i>Deep clean of ALL filtration pods.</i>			

Quarterly Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
N/A			

Quarterly Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
N/A			

Quarterly Task Sheet - Legionella

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
<i>Microbiological monitoring – total count</i>			
<i>Microbiological monitoring – Legionella count</i>			

Appendix A05. Annual Maintenance Sign-off Sheet

Annual Task Sheet - Aquaponics System

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
(refer to section 4.0 Deep Clean)			

Annual Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
Clip Wings			

Annual Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
N/A			

Annual Task Sheet - Legionella

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
(refer to section 4.0 Deep Clean)			
(Please See Appendix C01 Risk Assessment: Control of Legionella in Technical Food Systems)			

Appendix A06. Additional Maintenance Sign-off Sheet

Additional Maintenance - Aquaponics System

TASK	Date	Completed By	Signed off
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			
<i>Fish tank deep clean after tank harvest</i>			

TASK	Date	Completed By	Signed off
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			
<i>NFT Channel deep clean after harvest</i>			

TASK	Date	Completed By	Signed off
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			
<i>Washing of media balls.</i>			

Appendix A07. Poultry Maintenance Sign-off Sheet

MASTER COPY

[illegible]

✓ = Checked & Washed as required.

= Number or Amount.

CL = Deep Clean

Appendix A08. Aquatic Feeding Sign-off Sheet

MASTER COPY

[illegible]

PLEASE REFER TO THE MANUAL TO ENSURE UP-TO-DATE QUANTITIES

Appendix A09. Incident Report Log

Incident Report Log:

[illegible]

Appendix A10. Repairs Report Log

Repairs Report Log:

[illegible]

Appendix A11. Alterations Log

Alterations Log:

[illegible]

Appendix A12. System Filling Log

System Filling Log:

[illegible]

Appendix B01. Risk Assessment: The control of Legionella in Technical Food Systems

Risk Assessment – Control of Legionella in Technical Food Systems.

1.0 Legionella and Legionnaires Disease

1.1 What is Legionella?

Legionnaires' disease, or Legionellosis, is an infectious disease caused by bacteria belonging to the genus *Legionella*.

The term 'Legionnaires' disease' originated in 1976 following an outbreak of serious respiratory disease at a convention of the Pennsylvania Branch of the American Legion, which led to the eventual discovery and identification of the responsible bacteria, *Legionella pneumophila*. Since its discovery, over 40 species of *Legionella* bacteria have been identified, although only a handful are known to cause infections in humans.

Legionella pneumophila, an organism found in cooling towers, air conditioners and other water systems.

Legionella longbeachae, a species commonly found in potting mix.

1.2 The factor of risk.

Legionella bacteria are natural inhabitants of fresh water systems such as ponds, streams, lakes, rivers, soil, mud and underground water. While low levels of bacteria are normal, *Legionella* can thrive in warm, moist conditions. *Legionella pneumophila* can be transmitted via inhalation of water droplets in aerosol form, which can potentially lead to Legionnaires infection. The risk of developing Legionnaires disease increases when people are exposed to infected environments generated through recirculating water systems, such as aquaponics.

The bacteria found in drinking and washing water can contain low numbers of *Legionella* bacteria is not known to result in infection.

Legionella longbeachae, can also be transmitted via aerosols or dust from contaminated gardening soils, such as potting mix, mulches and composts.

Rates of *Legionella* infection increase in people with lowered immune systems. This means that young, healthy people rarely get infected by *Legionella*. Factors increasing the likelihood of illness from *Legionella* infection include:

- Smoking;
- Chronic heart or lung disease;
- Diabetes;
- HIV/AIDS;
- Some forms of cancer;
- Steroid use or other immunosuppressive medication;
- Renal disease or kidney failure;
- Being over 50 years of age;
- Being of male gender; and
- excessive alcohol consumption.

The risk of contracting Legionnaires' disease can be reduced to a very low level through the careful design, installation and regular maintenance of aquaponic systems and the potential sources of aerosol. In addition, the safe handling of potting mix and other garden soils will reduce the risk of inhaling contaminated aerosols.

Infection from person to person, or from animals to person, does not occur.

1.3 Forms of Infection to be aware of

The mode of transmission varies depending on the particular strain of *Legionella* bacterium, but the disease is usually transmitted through the inhalation of contaminated aerosols.

Legionella infection is known to take two distinct forms, in particular:

- Legionnaires' disease, which is a form of pneumonia caused by an acute bacterial infection of *Legionella*; and
- Pontiac fever, which is a flu-like illness with symptoms including fever, chills and headaches.

The incubation period ranges from four hours to three days, and up to 95% of people exposed to the disease will become ill. Pontiac fever is not usually fatal. Infection is usually low in healthy individuals, although people with compromised immune systems are at an increased risk of infection. The mortality rate for Legionnaires' disease is about 5%.

1.3.0 Symptoms of infection

Early symptoms of Legionnaires' disease are often 'flu like', and can include some or all of the following:

- A fever (up to 40°C);
- Chills;
- Aching muscles and joints;
- A dry cough;
- Headaches (often severe);
- Tiredness;
- Gastro-intestinal disorders;
- A loss of appetite; and
- A shortness of breath.

1.3.1 Detection and diagnosis

The incubation period for Legionnaires' disease is usually two to ten days. However, in most cases, it will be up to five to six days before symptoms appear. Acute infections can affect many bodily systems, leading to diarrhoea, vomiting, mental confusion and kidney failure. In severe cases, Legionnaires' disease can be fatal.

Diagnosis is made by means of blood or urine tests, and/or identifying the organism in sputum and respiratory secretions

1.4 Conditions for growth of Legionella

The proliferation of *Legionella pneumophila* in water systems is the result of interrelationships between temperature, environmental micro-organisms and sediments, and the chemical composition of waters.

The proliferation of *Legionella* is known to be promoted by:

- A wet, warm environment (temperature range of 20°C - 45°C);
 - Stagnation or low water turnover;
 - High microbial concentration, including algae, amoebae, slime and other bacteria;
 - Presence of biofilm, scale, sediment, sludge, corrosion products or other organic matter;
- and
- degraded plumbing materials, such as rubber fittings, which may provide nutrients to enhance bacterial growth.

Under laboratory conditions, the optimal temperature for *Legionella* bacteria is 37°C. Significant

multiplication of the bacteria is generally restricted to temperatures between 20°C and 45°C, and maximum growth occurs within the range of 35°C to 43°C. Environments of 50°C or higher temperatures are sufficient to kill the bacteria.

1.5 The risk of *Legionella* in Aquaponics

Legionella bacteria are natural inhabitants of fresh water systems such as ponds, streams, lakes, rivers, soil, mud and underground water. While low levels of bacteria are normal, *Legionella* can thrive in warm, moist conditions.

In general, the sources of *Legionella* bacteria in recorded outbreaks of Legionnaires' disease have been traced to either large air conditioning plants or hot water distribution systems that have been incorrectly commissioned or poorly maintained. Organisms can enter fixtures either through the water supply or from aerosols produced by other (nearby) affected fixtures. Aquaponics is a closed water circulatory system that encourages certain bacteria growth and has the potential for temperature differentiation within the system meaning the risk of *Legionella* contamination must be considered.

Any source with the potential to create water aerosols has the potential to transmit the disease when the water is contaminated with *Legionella*.

2.0 RISK ASSESSMENT

The risk assessment will take account of:

- The water temperature
- The presence of stagnant water
- Sediment build up
- The potential for aerosol formation
- The likely risk to those who will inhale the aerosol
- The likely risk to the public visiting the Biospheric Foundation inhaling the aerosol
- The means of preventing or controlling the risk

2.1 The water temperature

The water temperature of the system will be **low** risk. It will be maintained at 12°C - 16°C this is below the specified temperature zone for *Legionella* bacteria proliferation.

The presence of stagnant water:

The risk of stagnant water occurring in the aquaponics system is **low**. A constant flow of water is crucial to the productivity and efficiency of the system and as such the system has been designed to encourage a continuous flow.

2.2 Sediment build up

The risk of sediment build up in the aquaponics system is **moderate**. Solid fish waste is contained within the system to be utilized as a nutrient source for the crops. The fish waste is encouraged to move around the system where it is broken down and ionized, reducing the risk of sediment build up.

2.3 The potential for aerosol formation

There are two particular areas of the aquaponics system that can be identified as **low** risk for the formation of aerosol. The Mineralisation Bank and the Window Growing System both involve the open flow of water between containers, this open flow has the potential for splashing, however the risk of spraying and aerosol forming is low. The mineralization bed has an internal plastic sheet and an external acrylic cladding which reduces the chance of inhalation of vapour. The window system, has a carefully designed growing bag system, which has a long tubular output from each bag, which helps to minimize splashing.

2.4 The likely risk to those who will inhale the aerosol

The risk to those exposed to aerosol is **low**. The people likely to receive exposure are those who have been recruited to harvest the crop, a physical activity that requires good physical health and agility. Based on information outlined in section 1.2 the factor of risk is low.

2.5 The likely risk to the public visiting the Biospheric Foundation of inhaling the aerosol

The risk to the public of inhaling contaminated aerosol while visiting the Biospheric Foundation is **low**. The public will not have access to any area of the aquaponic system where splashing occurs and contaminated aerosol could potentially be released.

3.0 PREVENTING OR CONTROLLING THE RISK

3.1 Design and installation

The primary objective is to avoid conditions that permit *Legionella* to proliferate and to avoid creating a spray or aerosol.

This can be achieved by:

- Avoiding water temperatures between 20°C and 45°C. Water temperature is a particularly important factor in the control of the risk. This particular aquaponics system will be maintained at a temperature range of 12°C - 16°C.
- Water temperature is monitored continuously via a Siemens control panel. In the event that the water temperature reaches 20°C, a water change will be conducted to reduce the temperature and water samples will be taken for testing. If the water temperature were to reach 25°C the whole system will be shut down and further samples would be taken for testing. (See water testing for further information)
- Avoiding water stagnation. Stagnation may encourage the growth of biofilm that can harbour *Legionella* and provide local conditions that encourage its growth. If water is allowed to stand for long periods in warm buildings or in hot weather its temperature is more likely to rise above 20°C. All pipes within the system have been laid-to-falls to encourage flow and eliminate the possibility of stagnant water within the system. The water within the tanks is cycled at a rate of 9000L per hour meaning each 750L tank will be fully cycled every hour.
- Designing the system to encourage a continuous flow of water throughout the whole system as to avoid the build-up of sediment. A build up of sediments may harbour bacteria or provide a nutrient source for them, however removing the solid fish waste is not a viable option as it would reduce the productivity and efficiency of the system and eliminate the research possibilities. Sufficient pumps have been included within the system to ensure a continuous flow of water within the system.
- In-line **UV-filtration** has been incorporated into the design of the aquaponic systems. At least 3 UV-filters will be active at a time, strategically located to treat the water as it passes through the most high risk areas of the system. These are – 1x to treat the water as it is piped from the fish tanks to the Mineralisation Bank, 1x to treat the water as it is piped from the Mineralisation Bank into the Window Growing system, 1x to be treat the water as it is pumped from the Window Growing system to the NFT growing area on the roof.
- The Window Growing systems have been designed to minimise the potential of water splashing and creating aerosol. Pipes will direct the flow of water from the bottom of one grow bag and finish no less than 3cm above the media line of the next to reduce the risk of splashing.
- The Mineralisation Bank uses a continuous flow method of drainage and a 30mm downpipe to direct the flow of water between the filtration beds. The inner pipe of the siphon will span the complete distance from one filtration bed to another, ensuring the water is fully contained within the walls of the filtration

beds. This will reduce the risk of splashing. The Mineralisation bank as a whole will be fully clad in 10mm thick polycarbonate sheeting to reduce the risk of aerosol being released.

- The fish tanks are also enclosed within the Aquaponics Lab, a fully clad structure only accessible by workers.
- Appropriate respiratory PPE (Personal Protective Equipment) should be worn to minimise the risk of inhaling water droplets contaminated by *Legionella* bacteria during harvesting of the Window Growing systems and exception and maintenance of the Mineralisation bank. PPE to protect the eyes should also be worn, eg goggles, a face shield or a full face respirator.
- An adequate water testing regime will ensure the level of legionella bacteria are monitored and recorded on a monthly basis. These tests are to be carried out by a suitable and relevant professional body. (TO BE ARRANGED BY THE BIOSPHERIC FOUNDATION)
- Ensuring that the system operates safely and correctly and is well maintained.
- Keeping records of the precautions implemented and any specialist maintenance required.
- Ensuring all pipework are free of burrs reducing the risk of sediment build up and corrosion within the pipes.
- All joins and fixings will be carefully bonded to ensure no compound is pushed into the pipe creating areas for sediment collection.
- Design features will facilitate the cleaning and control of degradation of the infrastructure. All elements of the systems infrastructure are modular to enable easy maintenance, repair and replacement.
- The materials used as system components where possible should not encourage microbial or fungal growth.
- The materials used within the aquaponics system are to be made from corrosion-resistant materials, and designed for ease of maintenance and food safety. Internal surfaces are to be smooth-faced, and designed to facilitate cleaning;
- All sumps can be drained and sediment can be easily removed or preferably, where possible encouraged to move through the system to be broken down.
- The location and orientation of piping is out of direct sunlight as far as practicable.
- The original windows of the building that will incorporate a Window Growing system will remain closed to prevent aerosol release from within the building.
- Easy and safe access for maintenance, particularly for cleaning purposes, including safe access for tasks done at heights.
- There are provisions in place that cater for the shutdown of the entire system to facilitate maintenance.
- Draining facilities such as manual siphons allow for fast drainage of the fish tanks and a gravity reliant design ensures full drainage of the whole aquaponics system.
- The individual pipes and all elements of the aquaponics system are to be cleaned and thoroughly flushed before being brought into service.
- All members and volunteers of the Biospheric Foundation will be made aware of the risks associated with legionella and the symptoms of legionella infection.
- Appropriate signage will be displayed informing visitors to the building to seek medical advice if they experience flu-like symptoms after their visit and to mention the possibility of legionella infection.

3.2 Operation and maintenance

The aquaponics system will be examined under normal working conditions for:

- Signs of uncharacteristic microbial growth;
- Algae;
- Water leaks;
- Splashing; and
- blockages or restrictions.

The aquaponics system will be operated and maintained using a risk based approach, which includes:

- Inspections daily as part of the regular maintenance routine;
- Regular microbiological monitoring; and
- cleaning as necessary at intervals not exceeding 12 months.

Cleaning should include the physical cleaning of the aquaponics system, draining of the entire water system. This should include:

- Flushing and cleaning before start-up if the system is only used seasonally;
- If the aquaponics system has been out of use and has not been dry
- High-pressure cleaning of all internal wetted surfaces, particularly their sumps and fill.
- The aquaponics system has been extensively modified or disturbed.

The aquaponic systems should be disinfected, drained, cleaned and then disinfected again when the installation:

- Contamination by legionella or other potential diseases has been identified.

Cleaning may also be necessary at regular intervals if the system, the state of the premises, or the results of microbiological monitoring indicate it is necessary. In such cases, it is important to ensure that all parts of the system, including storage or breeding tanks and associated filter systems, are cleaned with high-pressure steam where possible, not just those which are readily accessible. Due to the nature of this food producing aquaponics system the water cannot be chlorinated.

Cooling water systems that have been shut down on a seasonal basis, or for more than 30 days, should be cleaned and suitable water treatment reinstated before start-up.

3.3 Manuals and records

Operating and maintenance manuals and maintenance records will be available for workplace equipment and systems. The operating and maintenance specifications and manuals will be provided by the design team.

Where applicable, manuals and records will include:

- A risk assessment and associated system specific management plan;
- Physical details, including drawings of the equipment and systems, including associated pipe work;
- Water treatment testing, maintenance and management; (TO BE ARRANGED BY THE BIOSPHERIC FOUNDATION)
- Recommended cleaning methods and dismantling instructions;
- Operating and shutdown procedures;
- Date, item of equipment or system and nature of service performed; (TO BE PERFORMED BY THE BIOSPHERIC FOUNDATION)
- Water treatment reports and records; (TO BE ARRANGED BY THE BIOSPHERIC FOUNDATION)
- Microbiological reports and records; (TO BE ARRANGED BY THE BIOSPHERIC FOUNDATION)
- Roles and responsibilities associated with system operation; (TO BE ARRANGED BY THE BIOSPHERIC FOUNDATION)
- A defect and corrective action log; (TO BE PERFORMED BY THE BIOSPHERIC FOUNDATION)
- Evidence of awareness training for individuals responsible for management and maintenance of the system; and (TO BE ARRANGED BY THE BIOSPHERIC FOUNDATION)
- the name of the person or company performing the service. These manuals and records should be readily available to workers who may require the information. (TO BE ARRANGED BY THE BIOSPHERIC FOUNDATION)

3.4 Modular Assessment of Risk

Step 1: Identify potential source of infection.

Are workers exposed to aerosol?
What is the temperature of the water?

Step 2: Assess the risk of infection

Is the system regularly maintained and cleaned?
Are the occupants of the building particularly susceptible?
Is the water routinely tested for chemical and microbiological parameters and what are the results?
Are workers wearing appropriate protective equipment?
Are there any design alterations or additions that could be implemented?

Step 3: Control the risk

Design appropriate solutions to respond to the risk
Appropriate maintenance, operational and cleaning program in place.
If necessary, water treatment.
Appropriate protective equipment in use.
Testing showing effective microbiological control.

3.5 Minimum Maintenance Table

System	Task	Frequency of inspection
Aquaponics System	Monitor water quality,	Daily
	Microbiological monitoring – <i>total count</i>	Quarterly
	Microbiological monitoring – <i>Legionella</i>	Quarterly
	System inspection including observation of internal condition of sump, tank, filtration beds, grow bags, NFT channels and water	Daily
	System component inspection including filters, pumps and pipes.	Daily

3.6 Control Strategy

Test result (cfu*/mL) (<i>Legionella</i>)	Required control strategy
Not detected (<10)	System under control. Maintain monitoring and treatment program.
Detected as <1,000	<p>Immediate online action (reduce water temperature).</p> <p>Review control strategy.</p> <p>Re-test water within three to seven days of plant operation, and assess if further remedial action is necessary.</p>
Detected as ≥1,000	<p>Immediate shut down of system</p> <p>Offline decontamination (chlorine based biocide).</p> <p>Review control strategy.</p> <p>Re-test water within three to seven days of plant operation, and assess if further remedial action is necessary.</p>

cfu = colony forming units

APPENDIX C01. Full Specification

Aquaculture Lab:

Swell UK:

(1) Oase Aquarius Universal 21,000 <http://www.swelluk.com/pond/pond-pumps-62/fountain-pumps-293/oase-aquarius-universal-pro-pond-pumps-21000-40000-lph--5973.html> - £599.99

Hydro-Grow:

(1) Hailea ACO-9810 air pump [http - www.hg-hydroponics.co.uk/hailea-ac0-9810-high-power-low-noise-air-pump-3362-p.asp](http://www.hg-hydroponics.co.uk/hailea-ac0-9810-high-power-low-noise-air-pump-3362-p.asp) - £39.99

Koi Zone:

(1) Hailea V30 air pump - <http://www.koi-zone.co.uk/Aeration-For-Koi-Ponds/Hailea-Airpumps-sc-1718.html> - £42.99

(1) Hailea V60 air pump - <http://www.koi-zone.co.uk/Aeration-For-Koi-Ponds/Hailea-Airpumps-sc-1718.html> - £57.99

Hydrohobby:

(12) – VolumeAir 150mm Disk Airstones - <http://www.hydrohobby.co.uk/volumeair-150mm-disc-airstone.html> - £4.99 (£

eBay shiney-d:

(5) 10 x 50mm Elbow [grey] – http://www.ebay.co.uk/itm/Push-fit-waste-knuckle-bend-elbow-32-40-50-mm-wh-blk-gr-/110727289797?pt=LH_DefaultDomain_3&var=&hash=item19c7dc5bc5 - £3.62 (£36.20)

(7) 10 x 50mm Tee [grey] - http://www.ebay.co.uk/itm/Push-fit-waste-water-swept-tee-32-40-50-mm-wh-blk-gr-/110727308992?pt=LH_DefaultDomain_3&var=&hash=item19c7dca6c0 - £3.62 (£36.20)

Plumbase:

(15) 18m x 50mm Pipe - <http://www.plumbase.com/tprod99731/section2072/polypipe-50mm-waste-pipe-3mt-www51.html> - £7.50/3m (£45.00)

(24) 27m x 32mm PVC Pipe [white] - <http://www.plumbase.com/tprod99696/section2072/polypipe-32mm-waste-pipe-3mt-www11.html> - £4.74/3m (£42.66)

Professional Building Supplies:

(9) 12 x 32mm Coupler [white] - <http://www.professionalbuildingsupplies.co.uk/products/push-fit-waste-white-41/32mm-push-fit-white-coupling-234.aspx> - £0.95 (£11.40)

(9) 12 x 50mm-32mm reducer [grey] -
<http://www.professionalbuildingsupplies.co.uk/products/push-fit-waste-grey-39/50mm-push-fit-grey-x-32mm-reducer-176.aspx> - £2.17 (£26.04)

eBay bathroomsandkitchens4less:

(12) 12 x 32mm Tee [white] -
http://www.ebay.co.uk/itm/200614978543?var=500019208800&ssPageName=STRK:MEWAX:IT&_trk_sid=p3984.m1423.l2649 - £1.75 (£21.00)

(21) 25 x 32mm Elbow [white] -
http://www.ebay.co.uk/itm/200614978324?var=500019208776&ssPageName=STRK:MEWAX:IT&_trk_sid=p3984.m1423.l2649 - £1.25 (£31.25)

Filtration Unit:

Swell UK:

(1) Oase Aquarius Universal 21,000 - <http://www.swelluk.com/pond/pond-pumps-62/fountain-pumps-293/oase-aquarius-universal-pro-pond-pumps-21000-40000-lph--5973.html> - £599.99

Koi Zone: (1) Hailea V60 air pump -
<http://www.koi-zone.co.uk/Aeration-For-Koi-Ponds/Hailea-Airpumps-sc-1718.html> - £57.99

Hydrohobby:

(8) – VolumeAir 150mm Disk Airstones - <http://www.hydrohobby.co.uk/volumeair-150mm-disc-airstone.html> - £4.99 (£39.92)

PVC Building Products:

(100) 32mm tank connectors - <http://www.pvcbuildingproducts.co.uk/32mm-tank-connector-for-push-fit-waste-pipes-1155-p.asp> - £0.85 (£85.00)

Amazon:

(5) 7 x 40mm-32mm barbed reducer -
<http://www.amazon.co.uk/Inline-hose-reducer-jointer-40mm/dp/-007PQ2XNO> - £2.99 (£20.93)

CMC Aquatics:

(1) 2 x 32mm valve - <http://www.cmcaquatics.co.uk/pond/pond-pipe-hose-fittings/pond-hose-pipe-fittings-valves/inline-valve-32mm-pond-hose> - £8.97 (£17.94)

Aquatics Warehouse:

(1) 2 x 40mm valve - <http://www.aquatics-warehouse.co.uk/blagdon-multi-hose-ball-valve.html> - £7.46 (£14.92)

Doncaster Plastics:

[contact 01302 350 066]

(2) 4 x 50mm to 38mm barbed hose reducer (no part number but have confirmed they can supply and deliver) - £3.83 (£15.32)

(2) 4 x 50mm to 1.5inch BSP hose adapter (part number 22PPADA) - £3.07 (£12.28) (2) 4 x 40mm Barbed Tee (part number 07PPHOSE) - £1.65 (£6.60)

(5) 10 x 32mm barbed elbow (part number 19PPHOSE) – £0.97 (£9.70) (15) 20 x 32mm barbed Tee (part number 06PPHOSE) - £1.05 (£21.00)

Discount Leisure Products:

(14) 16 x 32mm-20mm reducer -

<http://www.discountleisureproducts.co.uk/pond-supplies-c1/32mm-20mm-flexible-pond-hose-reducer-barbed-plastic-fitting-p937> - £1.99 (£31.84)

E.J. Wollard Ltd.:

(14) 16 x 20mm barbed valve - <http://shop.ejwoollard.co.uk/20mm-barbed-valve> - £1.15 (£18.40)

eBay ytpm34:

(2) 4 x 50mm rubber coupler - <http://www.ebay.co.uk/itm/2-Rubber-Coupling-50mm-PVC-waste-Pipe-Coupler-bnib-/370516729073> - £4.99 (£19.96)

Hydrospares:

(2) 4 x 50mm to 1.5inch -SP socket adapter- <http://www.hydrospares.co.uk/hot-tub-spares/plumbing-fittings-valves-hoses/pipe-fittings-threaded/threaded-socket-adaptor-pvc-threaded-female-bsp-socket-to-socket.htm> - £4.49 (£17.96)

Marine Bazaar:

(1) 2 x 25mm,32mm,38mm non return valve - <http://marinebazaar.net/product/277-158/Non-Return-Valve-for-25mm-32mm-38mm-hose> - £9.99 (£19.98)

Ponds 4 Fish:

(70) 80 x 32mm Double wire hose clip - <http://www.ponds4fish.co.uk/shop/eze-tight-double-wire-hose-clip-32mm-1-25-inch/> - £1.12 (£89.60)

(15) 20 x 40mm Double wire hose clip - <http://www.ponds4fish.co.uk/shop/eze-tight-double-wire-hose-clip-40mm-1-57-inch/> - £1.38 (£27.60)

Window System:

Swell UK:

(1) Oase Aquarius Universal 40,000 - <http://www.swelluk.com/pond/pond-pumps-62/fountain-pumps-293/oase-aquarius-universal-pro-pond-pumps-21000-40000-lph--5973.html> - £799.99

Machine Mart:

(1) Clarke Psv1A Dirty Water Submersible Pump
<http://www.machinemart.co.uk/shop/product/details/psv1a-pump> - £53.99

Ponds 4 Fish:

(15) 15 x 40mm Double wire hose clip - <http://www.ponds4fish.co.uk/shop/eze-tight-double-wire-hose-clip-40mm-1-57-inch/> - £1.38 (£20.70)

(25) 25 x 32mm Double wire hose clip - <http://www.ponds4fish.co.uk/shop/eze-tight-double-wire-hose-clip-32mm-1-25-inch/> - £1.12 (£28.00)

Amazon:

(3) 4 x 40mm-32mm barbed reducer - <http://www.amazon.co.uk/Inline-hose-reducer-jointer-40mm/dp/-007PQ2XNO> - £2.99 (£11.96)

CMC Aquatics:

(1) 1 x 32mm valve - <http://www.cmcaquatics.co.uk/pond/pond-pipe-hose-fittings/pond-hose-pipe-fittings-valves/inline-valve-32mm-pond-hose> - £8.97 (£8.97)

Aquatics Warehouse:

(1) 1 x 40mm valve - <http://www.aquatics-warehouse.co.uk/blagdon-multi-hose-ball-valve.html> - £7.46 (£7.46)

Discount Leisure Products:

(5) 6 x 32mm-20mm reducer - <http://www.discountleisureproducts.co.uk/pond-supplies-c1/32mm-20mm-flexible-pond-hose-reducer-barbed-plastic-fitting-p937> - £1.99 (£11.94)

E.J. Wollard Ltd.:

(5) 6 x 20mm barbed valve - <http://shop.ejwoollard.co.uk/20mm-barbed-valve> - £1.15 (£6.90)

eBay ytpm34:

(7) 8 x 50mm rubber coupler - <http://www.ebay.co.uk/itm/2-Rubber-Coupling-50mm-PVC-waste-Pipe-Coupler-bnib-/370516729073> - £4.99 (£39.92)

Doncaster Plastics:

[contact 01302 350 066]

(2) 3 x 50mm to 38mm barbed hose reducer (no part number but have confirmed they can supply and deliver) - £3.83 (£11.49)

(2) 3 x 50mm to 1.5inch BSP hose adapter (part number 22PPADA) - £3.07 (£9.21)

(2) 3 x 40mm Barbed Tee (part number 07PPHOSE) - £1.65 (£4.95)

(1) 2 x 40mm elbow (part number 20PPHOSE) - £1.29 (£2.58)

(3) 4 x 32mm barbed Tee (part number 06PPHOSE) - £1.05 (£4.20)

(2) 3 x 32mm elbow (part number 19PPHOSE) – £0.97 (£2.91)

(2) 3 x 50mm Tee (part number 08PPHOSE) - £6.08 (£18.24)

(5) 7 x 50mm hose mender (part number 30PPHOSE) - £3.57 (£24.99)

Hydrospares:

(2) 4 x 50mm to 1.5inch BSP socket adapter- <http://www.hydrospares.co.uk/hot-tub-spares/plumbing-fittings-valves-hoses/pipe-fittings-threaded/threaded-socket-adaptor-pvc-threaded-female-bsp-socket-to-socket.htm> - £4.49 (£17.96)

eBay autoperformanceonline:

(40) 45 x 12mm to 10mm tee reducer - http://www.ebay.co.uk/itm/12-10-12mm-Plastic-Reducing-T-Piece-Hose-Connector-Sili-/270698190621?pt=UK_CarsParts_Vehicles_CarParts_SM&hash=item3f06de971d - £2.45 (£110.25)

eBay ebiz96:

(10) 12 x 12mm to 10mm elbow reducer - http://www.ebay.co.uk/itm/12mm-10mm-EL-OW-AR-ED-REDUCER-Connector-Hose-JOINER-/160475550371?pt=UK_CarsParts_Vehicles_CarParts_SM&hash=item255d1692a3 - £2.69 (£38.28)

eBay a1homeimprovementsupplies:

[previous bought 900m from them]

(20) 24m x square white gutter (from original quote) - £2.16/2m (£25.92)

(10) 12 x square gutter stop ends – (from original quote) - £0.65 (£7.80)

Ponds 4 fish:

(5) 6 x 50mm tank connector - <http://www.ponds4fish.co.uk/shop/threaded-tank-connector-50mm-diameter-2-inch/> - £4.12 (£24.72)

East 2 Eden:

(100) 14lt High Grade Rectangular Plastic Washing Up Bowls (Green) - <http://www.east2eden.co.uk> £3.49 (£349.00)

Thames Valley Supplies:

(4) 1.4m x 10m @ 1.5mm Thickness Food Quality Approved Natural Rubber - White 60 IRHD - <http://www.thamesvalleysupplies.co.uk> £145.00 per roll (£580.00)

Thames Valley Supplies:

(3) 1.2m x 10m @ 1.5mm thickness White Silicone Sheeting - 60 IRHD - <http://www.thamesvalleysupplies.co.uk> £197.80 per roll (£593.40)

Gripple Limited:

(60) 2m Snap on Hook End Fixing, No.1 kit - www.gripple.com £3.31 (£198.60)

Gripple Limited:

(40) 1.5m Snap on Hook End Fixing No.1 kit - www.gripple.com £3.08 (£123.20)

SecureFix Direct:

(3) 10 x Split Bolt and Joint Clip - <http://www.securefixdirect.com> £7.00 per bag of 10 (£210.00)

Polytunnel:

Home Improvements:

(450m) Square Guttering 2m white - http://www.home-is.co.uk/index.php/square-line-gutter-system-114mm-white-square-line-gutter-c-594_602_603_682?osCsid=a2e5a765304188b601c75b1d7d26047c - £2.16/2m (£972.00)

(135) Square Gutter Stop-ends - http://www.home-is.co.uk/index.php/square-line-gutter-system-114mm-white-square-line-gutter-c-594_602_603_682?osCsid=a2e5a765304188b601c75b1d7d26047c - £0.65 (£87.75)

Liv Supplies:

(250) floplast gutter unions - http://www.livsupplies.co.uk/product_desc5.php?id=302 - £1.12 (£280)

Ponds 4 Fish:

(15) 20 x 40mm Double wire hose clip - <http://www.ponds4fish.co.uk/shop/eze-tight-double-wire-hose-clip-40mm-1-57-inch/> * £1.38 (£27.60)

(40) 50 x 32mm Double wire hose clip - <http://www.ponds4fish.co.uk/shop/eze-tight-double-wire-hose-clip-32mm-1-25-inch/> - £1.12 (£56.00)

Ray Grahams:

(200) 220x 13mm – 20mm hose clip - <http://www.raygrahams.com/products/110563-hi-grip-20mm-zinc-plated-hose-clip-13-20mm.aspx> - £0.47 (£103.40)

Amazon: (3) 4 x 40mm-32mm barbed reducer -
<http://www.amazon.co.uk/Inline-hose-reducer-jointer-40mm/dp/-007PQ2XNO> - £2.99 (£11.96)

CMC Aquatics:

(1) 2 x 32mm valve - <http://www.cmcaquatics.co.uk/pond/pond-pipe-hose-fittings/pond-hose-pipe-fittings-valves/inline-valve-32mm-pond-hose> - £8.97 (£17.94)

Aquatics Warehouse:

(1) 2 x 40mm valve - <http://www.aquatics-warehouse.co.uk/blagdon-multi-hose-ball-valve.html> - £7.46 (£14.90)

eBay ytpm34:

(2) 3 x 50mm rubber coupler - <http://www.ebay.co.uk/itm/2-Rubber-Coupling-50mm-PVC-waste-Pipe-Coupler-bnib-/370516729073> - £4.99 (£14.97)

Doncaster Plastics:

[contact 01302 350 066]

(2) 4 x 50mm to 38mm barbed hose reducer (no part number but have confirmed they can supply and deliver) - £3.83 (£15.32)

(2) 4 x 50mm to 1.5inch BSP hose adapter (part number 22PPADA) - £3.07 (£12.28)

(2) 4 x 40mm Barbed Tee (part number 07PPHOSE) - £1.65 (£6.60)

(8) 10 x 32mm barbed Tee (part number 06PPHOSE) - £1.05 (£10.50)

(2) 4 x 32mm elbow (part number 19PPHOSE) – £0.97 (£3.88)

(28) 30 x 20mm tee (part number 04PPHOSE) - £0.64 (£19.20) (20) 30 x 20mm elbow (part number 17PPHOSE) - £0.62 (£18.60)

Hydrospares:

(2) 3 x 50mm to 1.5inch BSP socket adapter- <http://www.hydrospares.co.uk/hot-tub-spares/plumbing-fittings-valves-hoses/pipe-fittings-threaded/threaded-socket-adaptor-pvc-threaded-female-bsp-socket-to-socket.htm> - £4.49 (£13.47)

Discount Leisure Products:

(10) 12 x 32mm-20mm reducer -
<http://www.discountleisureproducts.co.uk/pond-supplies-c1/32mm-20mm-flexible-pond-hose-reducer-barbed-plastic-fitting-p937> - £1.99 (£23.88)

(26) 30 x 20mm to 12mm reducer - <http://www.discountleisureproducts.co.uk/pond-supplies-c1/20mm-12mm-flexible-pond-hose-reducer-barbed-plastic-fitting-p934> - £1.50 (£45.00)

E.J. Wollard Ltd.:

(13) 15 x 20mm barbed valve - <http://shop.ejwoollard.co.uk/20mm-barbed-valve> - £1.15 (£17.25)
GroWell:

(26) 30 x 8 outlet manifold - <http://www.growell.co.uk/8-outlet-manifold-to-13mm-tee.html> - £2.50 (£75.00)
(26) 30 x 13mm tee - <http://www.growell.co.uk/8-outlet-manifold-to-13mm-tee.html> - £1.45 (£43.50)

Leaky Hose:

(26) 30 x 13mm hose stopend - http://www.leakyhose.co.uk/soaker-hose/Soaker_Hose_Stop_End_Connector-13mm.html - £1.42 (£42.6)

Return from roof:

Plumbase:

(65m) 72m x 50mm Pipe - <http://www.plumbase.com/tprod99731/section2072/polypipe-50mm-waste-pipe-3mt-wws51.html> - £7.50/3m (£180.00)

eBay a1homeimprovementsupplies:

(10m) 14 x square white gutter (from original quote) - £2.16/2m (£15.12)

(26) 30 x square gutter stop ends – (from original quote) - £0.65 (£19.50)

Ponds 4 fish:

(13) 15 x 50mm tank connector - <http://www.ponds4fish.co.uk/shop/threaded-tank-connector-50mm-diameter-2-inch/> - £4.12 (£61.80)

eBay vtpm34:

(13) 15 x 50mm rubber coupler - <http://www.ebay.co.uk/itm/2-Rubber-Coupling-50mm-PVC-waste-Pipe-Coupler-bnib-/370516729073> - £4.99 (£67.35)

eBay shineybd:

(26) 30 x 50mm Elbow [grey] – http://www.ebay.co.uk/itm/Push-fit-waste-knuckle-bend-elbow-32-40-50-mm-wh-blk-gr-/110727289797?pt=LH_DefaultDomain_3&var=&hash=item19c7dc5bc5 - £3.62 (£108.60)

(15) 20 x 50mm Tee [grey] - http://www.ebay.co.uk/itm/Push-fit-waste-water-swept-tee-32-40-50-mm-wh-blk-gr-/110727308992?pt=LH_DefaultDomain_3&var=&hash=item19c7dca6c0 - £3.62 (£72.40)

Piping:

Garden Site:

(16) 50mm hose x 30m -

http://www.gardensite.co.uk/Aquatics/-lack_Corrugated_Hose_50mm_2ins.htm - (£99.99 for 30m)

(41) 40mm hose x 50m -

http://www.gardensite.co.uk/Aquatics/Grey_Corrugated_Hose_40mm_1_12ins.htm - (£69.99 for 30m) + £3.49/m (£69.80)

(44) 32mm hose x 60m -

http://www.gardensite.co.uk/Aquatics/-lack_Corrugated_Hose_32mm_1_14ins.htm - (£99.98 for 60m)

(30) 20mm hose x 40m -

http://www.gardensite.co.uk/Aquatics/Black_Corrugated_Hose_20mm_34ins.htm - (£39.99 for 30m) + £2.00/m (£59.99)

Direct Chandlery:

13mm hose x 30m – [http://www.direct-](http://www.direct-chandlery.com/partnumber.asp?pnid=395456&source=googlebase&utm_source=googlebase&utm_medium=cpc)

[chandlery.com/partnumber.asp?pnid=395456&source=googlebase&utm_source=googlebase&utm_medium=cpc](http://www.direct-chandlery.com/partnumber.asp?pnid=395456&source=googlebase&utm_source=googlebase&utm_medium=cpc) - (£39.57 for 30m)

Hydroponics Market:

4mm hose x 40m -

<http://www.hydroponicsmarket.co.uk/value-4mm-pvc-pipe---10m-roll-1123-p.asp> - £4.00 (£16.00)

Irrigation Online:

20mm PVC pipe x 55m - <http://www.irrigationonline.co.uk/products/20mm-%252d-125mm-PVC-Pipe-.html> - £3.43/m (£37.73)

Machine Mart:

50mm Hose - <http://www.machinemart.co.uk/shop/range/guid/FD793EF5-0676-452A--40--74C1E5E4-79-?da=1&TC=SRC-suction> - £4.07/m

40mm Hose - <http://www.machinemart.co.uk/shop/range/guid/FD793EF5-0676-452A--40--74C1E5E4-79-?da=1&TC=SRC-suction> - £3.23/m

APPENDIX

P

APPENDIX P

Elevated aquaponic system - Handover training record

Queens University Aquaponic System Training:

Date of Training: 04/12/2013

The training given today has been delivered to a specific member of staff at the Biospheric Foundation named below. Queens is not responsible for the training of any other persons or third parties.

Named Member of Staff Benjamin van Ooij

This form is to confirm that the correct training has been given to and received by the named member of staff who is responsible for the aquaponic system within Irwell House. By signing below the named member of staff agrees that they have been given sufficient training to run the system in the absence of Queens University and that they understand the responsibility and dedication that is needed to keep the system healthy, and operating correctly. ^{4/12/13}
(amended) BJ

By signing this, the named member of staff is also promising to fill out all maintenance check sheets and keep a record of said sheets on a daily, weekly, monthly, quarterly, and annual basis. Additional to this the named member of staff will also complete and keep a record of all additional forms found in the appendix of the operations manual.

Named member of staff signature: BJ

Date: 04/12/13

Training Given by:

Andy Jenkins:

Sign: AJ

Date: 4/12/13

Natalie Hall:

Sign: NH

Date of Training: 04/12/2013

Morning Task Sheet - Training

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
SYSTEM ON:			
Morning Walk Around	✓	AS	BJ
Fish tanks receiving water	✓	AS	BJ
Air stones are operational	✓	AS+NH	BJ
Tank outflow pipes are connected and vertical.	✓	AS	BJ
Window splash check	✓	AS+NH	BJ
SYSTEM OFF:			
All three pumps turned off	✓	AS	BJ
Uncouple all three pumps	✓	AS	BJ
Inspect all pumps for blockages.	✓	AS	BJ
Remove any blockages.	✓	AS	BJ
Deep clean inside pumps.	✓	AS	BJ
Clean pump filters	✓	AS	BJ
Inspection and debris removal from sumps	✓	AS	BJ
Reconnect pipe work to pumps.	✓	AS	BJ
Test Pumps for spraying	✓	AS	BJ
Uncouple all three UV filters.	✓	AS	BJ
Remove all three UV filters from wall.	✓	AS	BJ
Disassemble all three UV filters.	✓	AS	BJ
Full clean of the inside of all three UV filters.	✓	AS	BJ
Reassemble all three UV filters	✓	AS	BJ
Fit UV filter back to wall	✓	AS	BJ
Pressure test all UV filters	✓	AS	BJ
Blockages in roof manifolds	✓	AS	BJ
Clean 4mm black hose	✓	AS	BJ
NFT channels free from obstruction.	✓	AS+NH	BJ
NFT debris baskets are clear of obstruction.	✓	AS+NH	BJ
Check window bungs	✓	AS	BJ
Clean return gutters on window system.	✓	AS	BJ
Ensure window debris collectors are clear.	✓	AS	BJ
SYSTEM ON:			
Bilge pump operating correctly	✓	AS	BJ
pH baths flowing.	✓	AS	BJ
Tank heaters operational	✓	AS	BJ
Clean two filter pumps	✓	AS+NH	BJ
Remove airlocks at every outlet valve.	✓	AS	BJ
Inspect all valves for blockages.	✓	AS	BJ
Remove valve blockages if necessary.	✓	AS	BJ
Inspect filtration pods for blockages.	✓	AS	BJ
Remove filtration blockages if necessary.	✓	AS	BJ
Fill the System (if required)	✓	AS	BJ
Final walk around	✓	AS+NH	BJ

Legionella PPE Requirements noted where applicable

✓

NH

04/12/15
Benjamin van Oort
Bouff

Daily Task Sheet - Training

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
AFTERNOON TASKS:			
SYSTEM ON:			
Feed the fish	✓	NH	BJ
Clean fish tank glass.	✓	NH	BJ
pH Level XX Check pH Level and record	✓	AS	BJ
Full walk around of aquaponic system	✓	AS + NH	BJ
Window splash check	✓	AS + NH	BJ
Ensure 4mm hose outlets are flowing	✓	AS	BJ
Remove airlocks at every outlet valve.	✓	AS	BJ
EVENING TASKS:			
SYSTEM ON:			
Remove all uneaten food from fish tanks.	✓	AS + NH	BJ
Remove airlocks at every outlet valve.	✓	AS	BJ
Clean out all lengths of 4mm black hose on roof.	✓	AS	BJ
Bilge pump operationg correctly	✓	AS	BJ
Air stones are operational	✓	AS + NH	BJ
Fish tanks receiving water	✓	AS	BJ
Final full walk around	✓	AS + NH	BJ

Daily Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Wash Drinkers and refresh water	✓	NH	BJ
Wash and refill Feeders	✓	NH	BJ
Check for eggs. (Twice Daily)	✓	NH	BJ
Check the coop for smell of ammonia	✓	NH	BJ
remove any large droppings in the nest box	✓	NH	BJ
Refill the Grain ball with corn	✓	NH	BJ
Observe the hens for approx 30mins.	✓	NH	BJ
Visual checks to assess health	✓	NH	BJ
Check behaviour of Bees	✓	NH	BJ

Daily Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Sweep Walkways	✓	NH	BJ
Inspect Chicken Coop	✓	NH	BJ
Inspect Bee Hive	✓	NH	BJ
Inspect all fencing	✓	NH	BJ
Fences are secure and damage free.	✓	NH	BJ
Water the Lawn	✓	NH	BJ

BJ

Weekly Task Sheet - Training

Date: XXX.XX.XXXX

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Chemical water tests.	✓	AS	BJ
Inspect sumps for wear or damage.	✓	AS	BJ
Clean sumps, dry, repair if required and refill	✓	AS	BJ
Clean window bags inside and out	✓	AS + NH	BJ
Repair any broken joints on window bags	✓	AS + NH	BJ
Clean NFT channels	✓	AS	BJ
Clean every side of fish tanks	✓	AS + NH	BJ

Chemical Tests:	Ammonia	Nitrite	Nitrate
Reading:	✓	✓	✓

Weekly Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Clean Coop & check for damage or infestation	✓	NH	BJ
Wash Feeders and drinkers thoroughly	✓	NH	BJ
Check for signs of rats and other	✓	NH	BJ
Check hens for lice and mites	✓	NH	BJ

Weekly Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
N/A	N/A	N/A	N/A

Day

Monthly Task Sheet - Training

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Change first set of 10mm clear hose	✓	AS	BJ
Place outlet bungs into the new 10mm clear hose	✓	AS	BJ
Clean and dry first set of 10mm clear hose	✓	AS	BJ
Change 4mm black hose and manifolds on roof	✓	AS	BJ
Clean and dry 4mm black hose and manifolds	✓	AS	BJ
Disassemble all push fit components	✓	AS	BJ
Reassemble push fit components	✓	AS	BJ
ALL joints to be inspected in detail	✓	AS	BJ

Monthly Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
(See Section 3.3.4.4 Month-by-month care plan)		NH	BJ

Monthly Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Completed By	Signed off
N/A	N/A	N/A	N/A

Monthly Task Sheet - Legionella

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Ensure UV filters are operational	✓	AS	BJ

Devy

Quarterly Task Sheet - Training

Date: XX.XX.XXX

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Deep clean of ALL piping.	<input checked="" type="checkbox"/>	AS	BJ
Deep clean of ALL filtration pods.	<input checked="" type="checkbox"/>	AS	BJ

- Lender P&E
check?

Quarterly Task Sheet - Poultry

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
N/A	N/A	N/A	N/A

* Extra Reading advised

NH

Quarterly Task Sheet - Roof Garden

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
N/A	N/A	N/A	N/A

Quarterly Task Sheet - Legionella

TASK	<input checked="" type="checkbox"/>	Trained By	Signed off
Microbiological monitoring - total count	<input checked="" type="checkbox"/>	NH	BJ
Microbiological monitoring - Legionella count	<input checked="" type="checkbox"/>	NH	BJ

Day

Additional Maintenance - Training

TASK	Date	Trained By	Signed off
Fish tank deep clean after tank harvest	✓	AS	BJ
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			
Fish tank deep clean after tank harvest			

TASK	Date	Trained By	Signed off
NFT Channel deep clean after harvest	✓	AS	BJ
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			
NFT Channel deep clean after harvest			

TASK	Date	Trained By	Signed off
Washing of media balls.	✓	AS	BJ
Washing of media balls.			
Washing of media balls.			
Washing of media balls.			
Washing of media balls.			
Washing of media balls.			
Washing of media balls.			
Washing of media balls.			
Washing of media balls.			
Washing of media balls.			

Ray

APPENDIX

Q

APPENDIX Q

BDP Facade-farm climatic analysis

Project : Bio-Productive facade Project
Bio-climatic Analysis

Job No: P2005542
Doc No: XXXX
Issue: Draft For discussion
Rev: 2
Date: Mau 2013

Issue Status

Revision	Description	Issued by	Date	Checked
0	Draft issue for Discussion	AAA	11/04/2013	09/04/2013
1	Draft issue for Discussion	AAA	16/04/2013	016/04/2013
2		AAA	03/05/2013	

BDP.

Contents

Executive Summary
Introduction

The Model (supermarket)
 Performance as a Vertical Farm
 Performance as an Internal Climate modifier

The Model (Irwell House)
 Performance as a Vertical Farm
 Performance as an Internal Climate modifier

Executive Summary

- The report is produced to capture the results of the bio-climatic analysis undertaken for the Greenius project.

The bio-climatic analysis was undertaken to test and prove the value of the bio-climatic façade as;

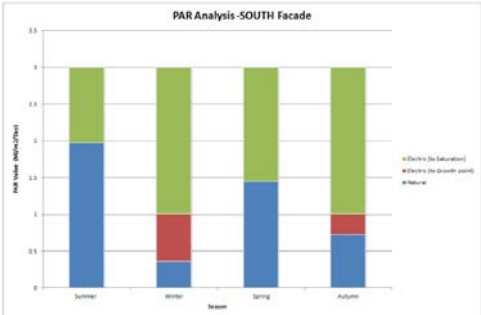
 - A tool for growing biomass and food produce within space constrained urban environments.
 - A tool for modifying the internal climate of the building its attached to.
- The results of the studies undertaken demonstrate that;

 - Lux and PAR levels achieved in the façade demonstrate it has real value as a vertical farm for the production of food crops. Levels are significantly higher within a south facing façade, which in turn significantly increase yield. Due to the lack of existing empirical data, or suitable modelling software the determine the mathematical ratio between physical biomass volume and external conditions (light, solar energy) - this will be tested in the Greenius façade installation at Irwell house.
 - The façade does reduce both heating and cooling loads for the building its attached to, and thus works to reduce the environmental operating costs, and carbon impact of the building. This will be further tested at the Irwell House test installation.

Summary results are provided on the following pages;

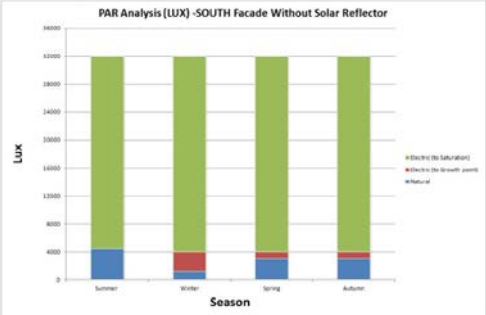
Executive Summary

Performance as a vertical farm



Research indicated that crops grow at an incident PAR level of 1MJ/m2/day, reaching a maximum growth rate at 3MJ/m2/day. As shown in the graphs above the daily PAR levels for growth are achieved in Spring and Summer without the need for artificial lighting.

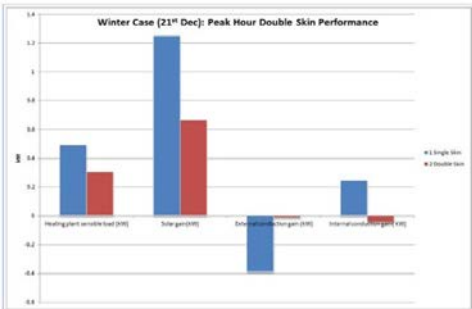
Ameet Update Graph - This should lux (don't mention PAR)



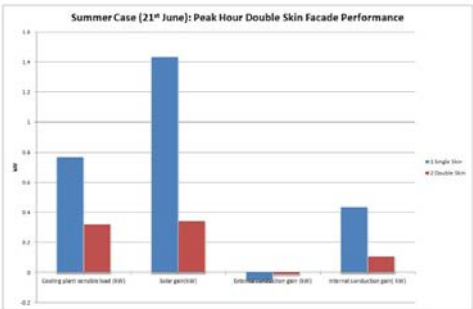
Research indicated that 4 000 lux is the required light level to plant growth, with 32 000 lux being the rate for maximum growth. The proportional rate of growth between these levels is not known. The overcast sky graphs above demonstrate that even on cloudy day growth levels are achieved in summer.

Executive Summary

Performance as an Internal Climate modifier



The right hand column on the Graph above shows how the provision of a south facing double skin aquaponic façade, is calculated to reduce the heating demand of the building its attached, on a typical winters day.



The right hand column on the Graph above shows how the south facing double skin aquaponic façade is calculated to more than halve the cooling demand of the building to which it is attached on a typical summers day. The plants also negate the need for proprietary fixed external shading.

Introduction

This report sits alongside the architects report, and the environmental control report, as a suite of BDP technical documents in support of the development of the bio facade hardware requirements for the UKTSB Greenius project.

The report is supplemented by reports from Queens University and the Biospheric foundation, relating to the hardware of the Aquaponic systems (as opposed to façade), and the economic and ecological operational models (software).

This report investigates the bio-climatic value of an Aquaponic façade system, looking at;

- Achievement of solar lux levels at plant level to facilitate plant growth, and any limitations of the models / need for further study.

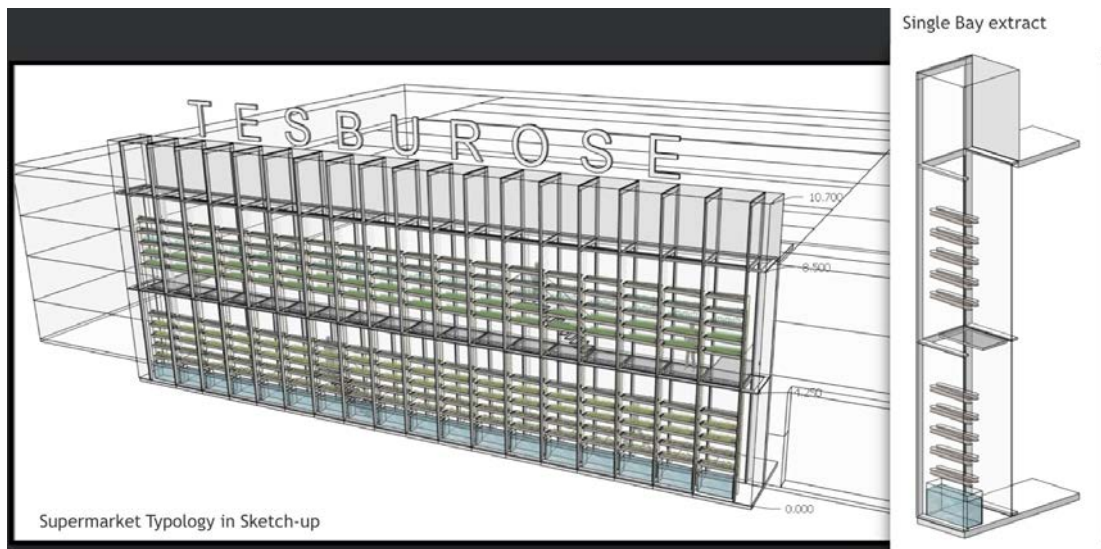
- Achievement of PAR (photo-synthetically active radiation) level at plant level to facilitate plant growth, and any limitations of the models / need for further study.

- The value of Aquaponic façade system in modifying the internal environmental within the building, considering solar gain, temperatures and heating and cooling loads, and any limitations of the models

The Model (supermarket)

In line with the architectural report a model was developed to test the environmental performance of the supermarket façade system.

The images on the next page show the suggested typology of the supermarket model in sketch up, along with the single bay which was extracted to simplify and speed up the bio-climatic analysis calculations. The results of the single bay model can be multiplied up to relate back to the full scale model.



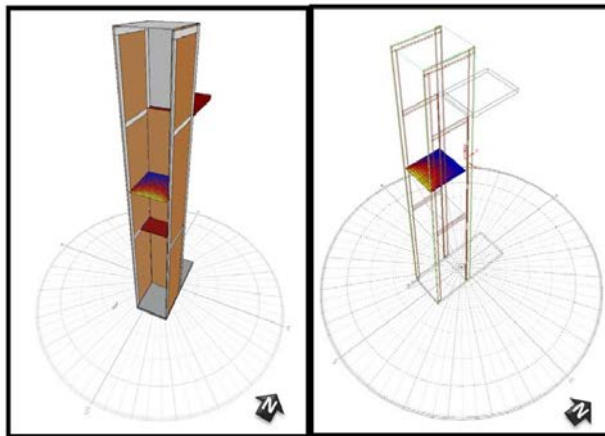


Image 1: Model and the Analysis grid plane at height of 6.3m

The model was extracted into Ecotect and the following parameters applied.

Material Properties

1	Single Glaze	
a	Reference type	DIAMANTE 10.00mm
b	U Value (W/m ² .K)	5.6
c	Solar Heat Gain Reflectance	0.88
d	Visible Transmittance	0.9
2	Double Glaze	
a	Reference type	SGG_coolite_skn_174
b	U Value (W/m ² .K)	1.4
c	Solar Heat Gain Reflectance	0.41
d	Visible Transmittance	0.67

PAR Analysis

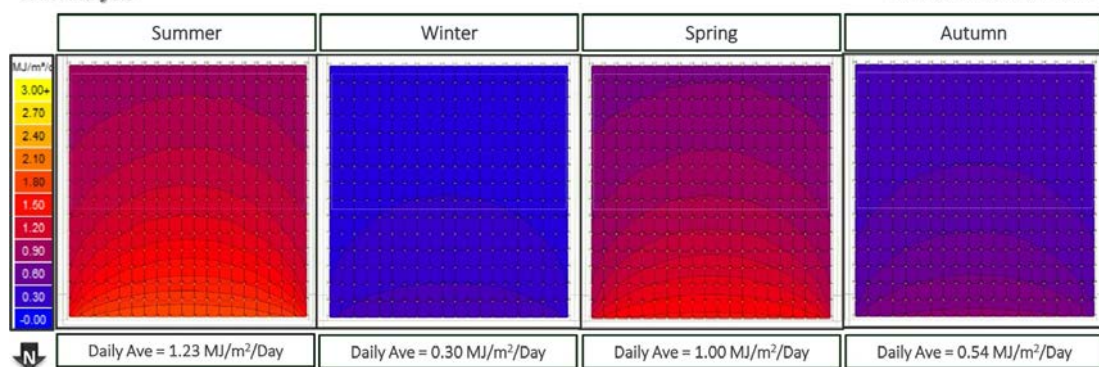
Research indicated that crops grow at an incident PAR level of 1MJ/m²/day, reaching a maximum growth rate at 3MJ/m²/day.

Four Ecotect models were produced, based on a North, South, East and West facing aspect. Each model was simulated for a typical summer, winter, spring and autumn day.

The results are presented on the following pages

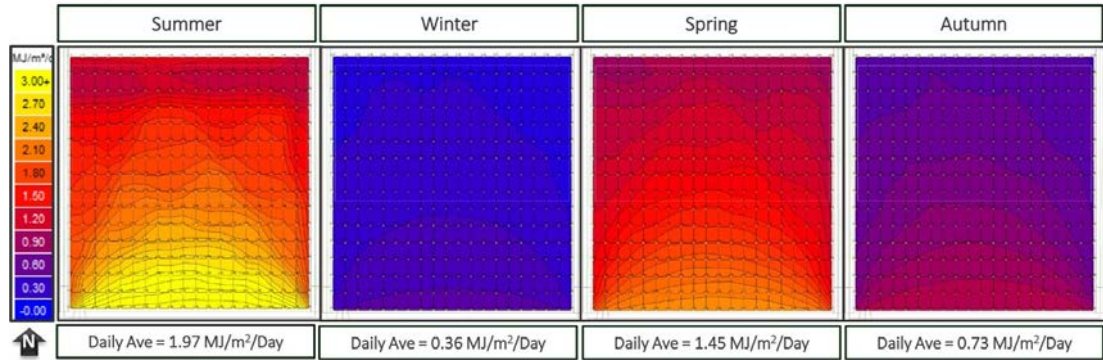
PAR Analysis

Bio-Facade facing NORTH



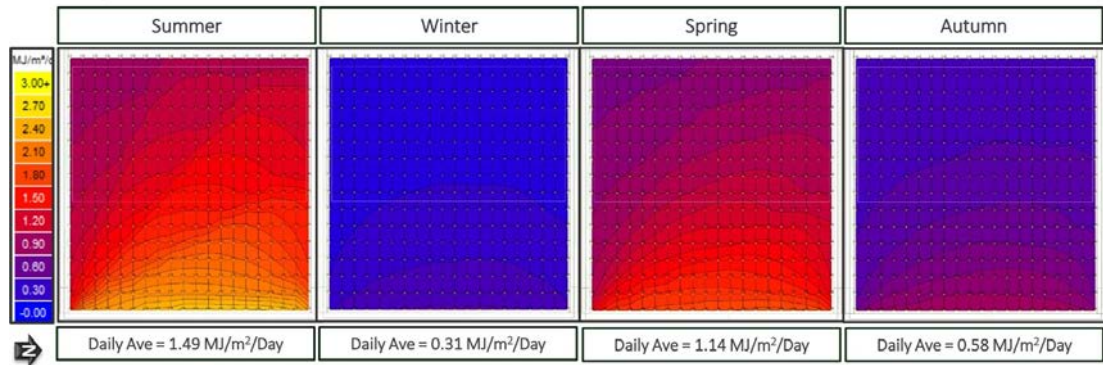
PAR Analysis

Bio-Facade facing SOUTH



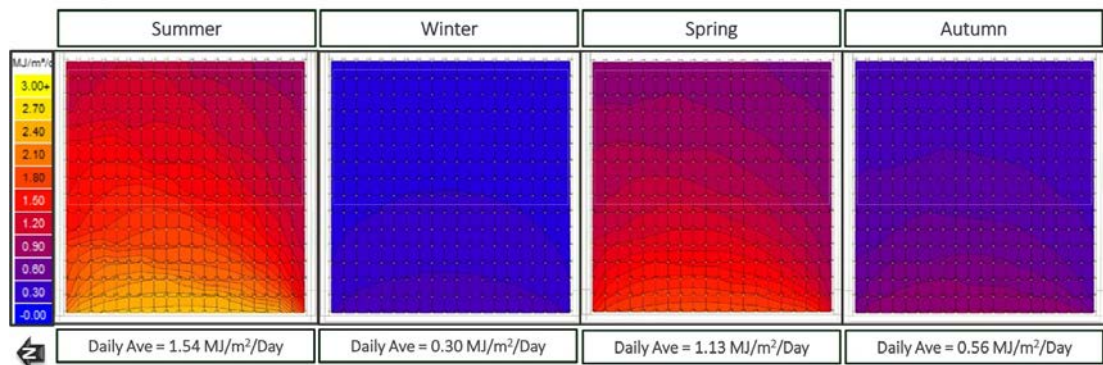
PAR Analysis

Bio-Facade facing EAST



PAR Analysis

Bio-Facade facing WEST



PAR Analysis

Comparison of analysis results

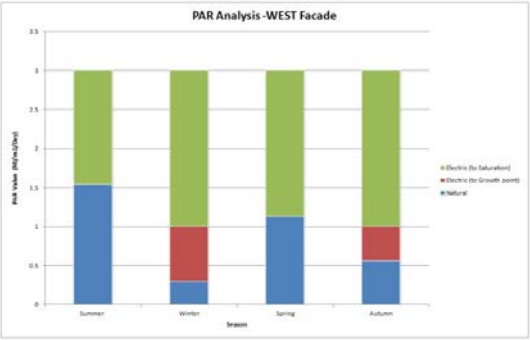
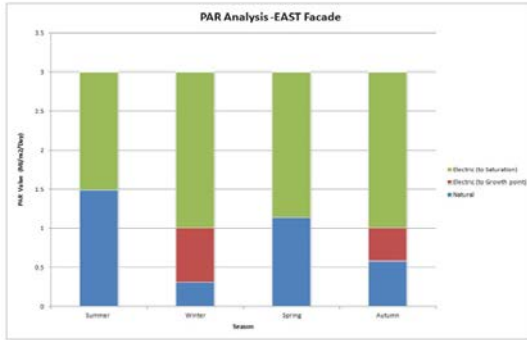
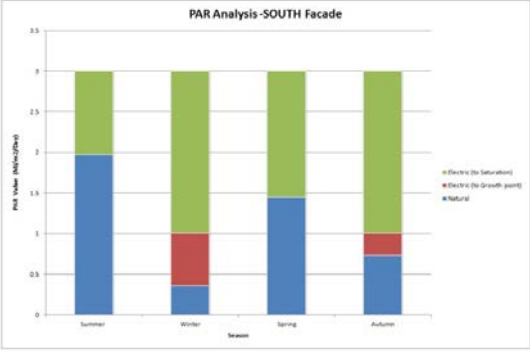
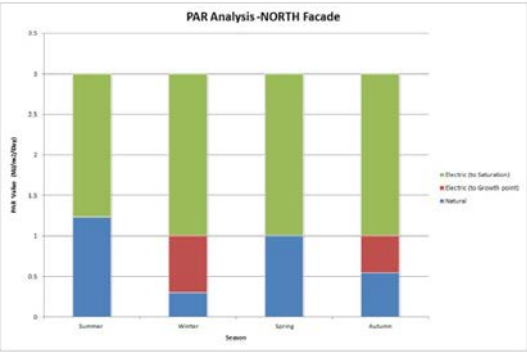
		MJ/m ² /day				
S/N	Direction	Summer	Winter	Spring	Autumn	Annual
1	South	1.97	0.36	1.45	0.73	1.13
2	North	1.23	0.30	1.00	0.54	0.77
3	East	1.49	0.31	1.14	0.58	0.88
4	West	1.54	0.30	1.13	0.56	0.89

		W/m ²				
S/N	Direction	Summer	Winter	Spring	Autumn	Annual
1	South	68.40	12.50	50.35	25.35	39.24
2	North	42.71	10.42	34.72	18.75	26.74
3	East	51.74	10.76	39.58	20.14	30.56
4	West	53.47	10.42	39.24	19.44	30.90

Simulation was run from 8.00-18.00 (8Hr) per day, therefore
1MJ/m²/Day = 34.7222W/m²

As shown in the tables, a south oriented facade would yield higher PAR values and can be considered as ideal to receive optimum PAR value, double that needed to stimulate plant growth

The charts on the following pages indicate, for the different models, how the daily PAR levels received from the sun relate to the levels required for growth and saturation.



Solar Reflector Analysis

Bio-Facade facing SOUTH

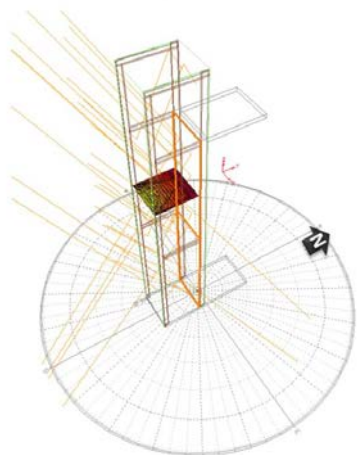


Image 2: Solar Reflector and the Analysis grid plane at height of 6.3m

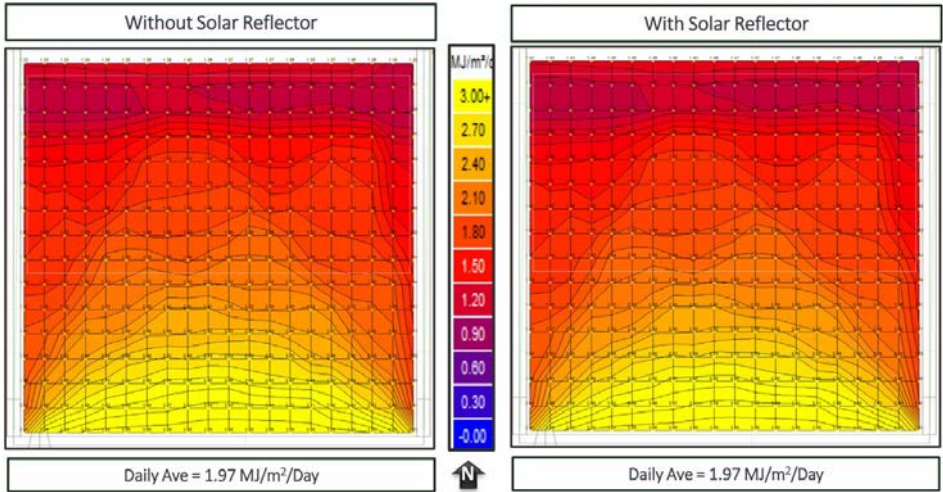
Material Properties

3	Solar Reflector	
a	Material	Stainless Steel
b	U Value (W/m2.K)	5.55
c	Solar Absorption	0.284
d	Reflectance	0.796
e	Visible Transmittance	0

A simulation was run to look at the effect of a solar reflector on the inner skin of the Aquaponic façade. However the model results on the following indicated little difference in daily lux or PAR level. This is not as was expected and will be tested empirically at Irwell house.

PAR Level - Summer from 8 am-6pm

Analysis on Horizontal grid at 6.3 m height



Lux Level

As an alternative to PAR lux levels within the aquaponic façade were. The research presented opposite was used to determine the growth start point (4000 lux) and the saturation point (32 000 lux)

It should be noted that due to issues with the software the models could only be run for an overcast day rather than a clear sky day.

Overcast Day - 10000 lux, Sunny Day - 100000 lux

Therefore the results presented represent worst case seasonal conditions, and thus if growth occurs in these conditions actual performance is likely to be significantly better.

The simulation was modelled for South facing only, and again performance of the solar reflector was not as expected.

Light in the greenhouse Agnote DPI/254

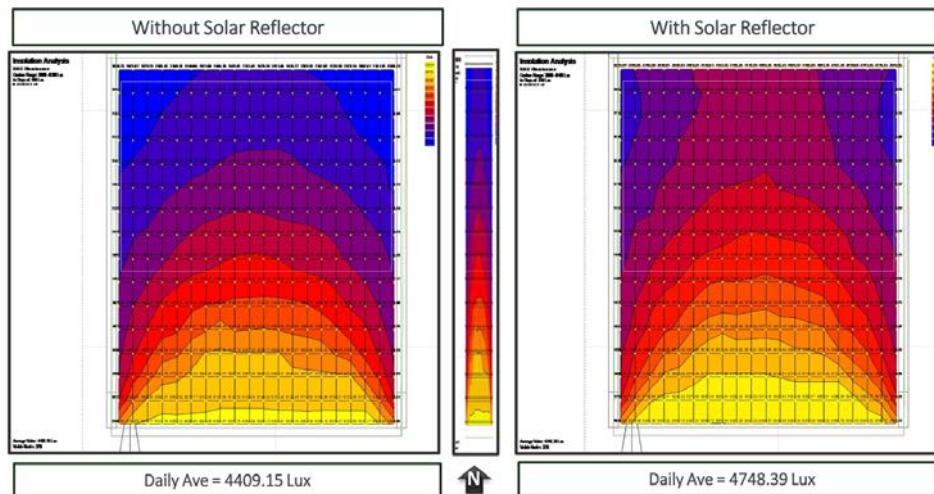
First edition, September 1999
Jeremy Badgery-Parker District Horticulturist (Protected Cropping) Gosford

Plants have an optimal intensity of light. This is the point at which the process of photosynthesis is maximised and plant growth is greatest. If the level of light is less, growth is reduced. In chrysanthemums, a light level of 4000 lux is just enough for the rate of photosynthesis to equal the rate of respiration. This is called the light compensation point. At this point, there is no net growth, but the plant can survive.

The point where an increase in light intensity will not increase photosynthesis any more is called light saturation. In many crops, an upper leaf would be saturated at around 32,000 lux.

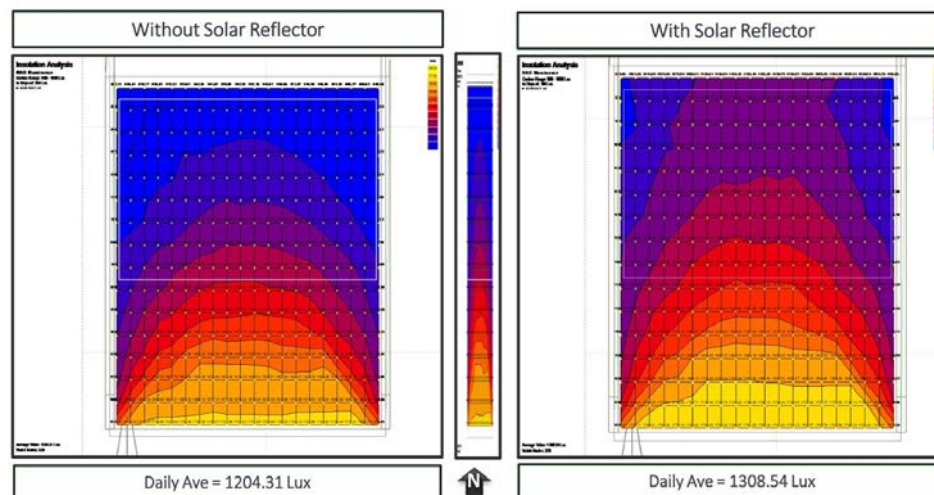
Lux Level - Summer Solstice, 21 June at 12.00 PM

Analysis on Horizontal grid at 6.3 m height



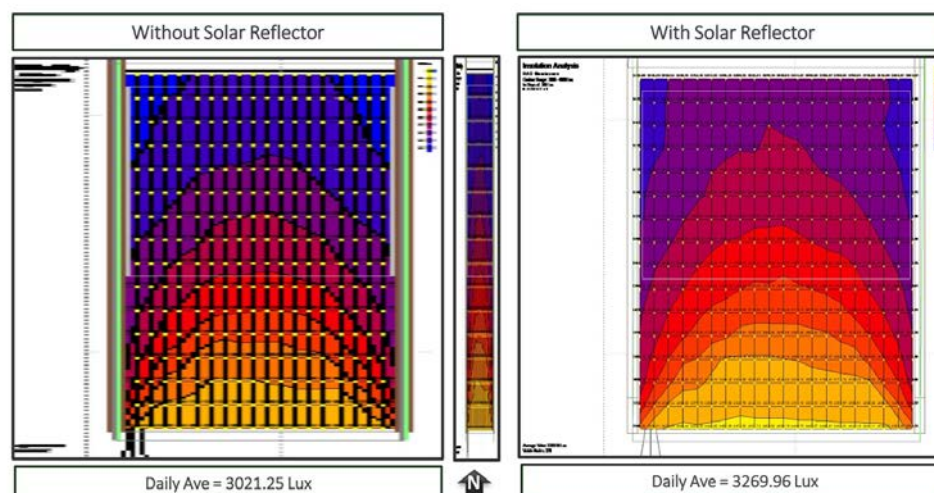
Lux Level - Winter Solstice, 21 December at 12.00 PM

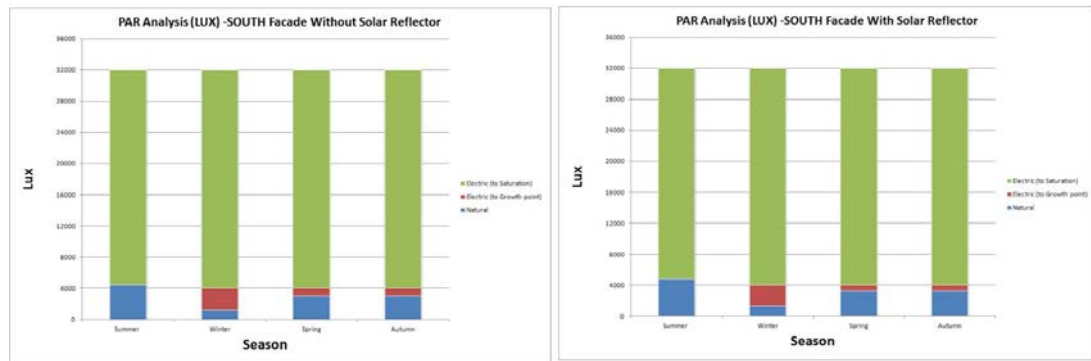
Analysis on Horizontal grid at 6.3 m height



Lux Level - Equinox, 21 March at 12.00 PM

Analysis on Horizontal grid at 6.3 m height





Research indicated that 4 000 lux is the required light level to plant growth, with 32 000 lux being the rate for maximum growth. The proportional rate of growth between these levels is not known. The overcast sky graphs above demonstrate that even on cloudy day growth levels are achieved in summer.

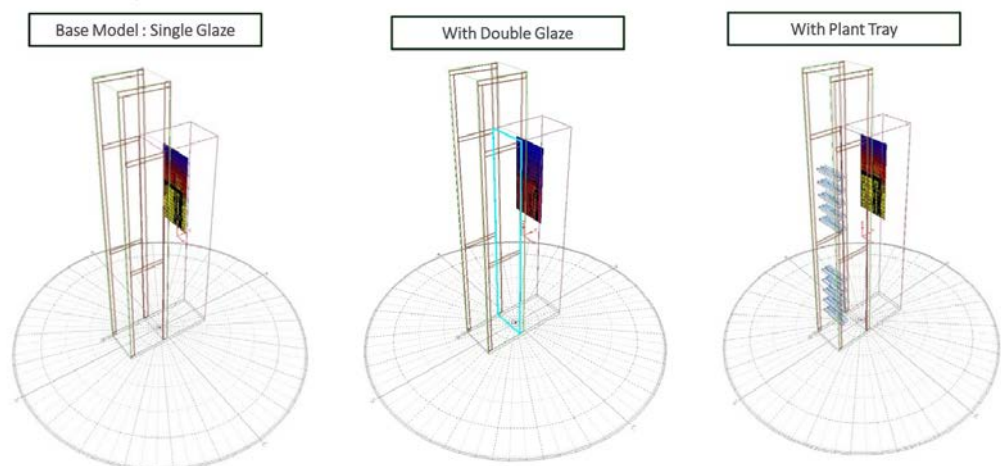
As clear sky lux level is 10 x higher than overcast, light levels of 50 000 lux could be expected in the façade on bright clear days, saturating the plants for maximum growth.

Bio-Climatic Modifier

Thermal analysis is presented in the following pages in order to;

- 1; Understand how the aquaponic façade effects solar gain being transferred into the any internal spaces adjacent to the façade.
2. Understand how heating loads (in winter) and heating gains (in summer) in adjacent internal spaces may be effected by the façade construction. As shown the aquaponic façade works well in reducing both heating and cooling loads.

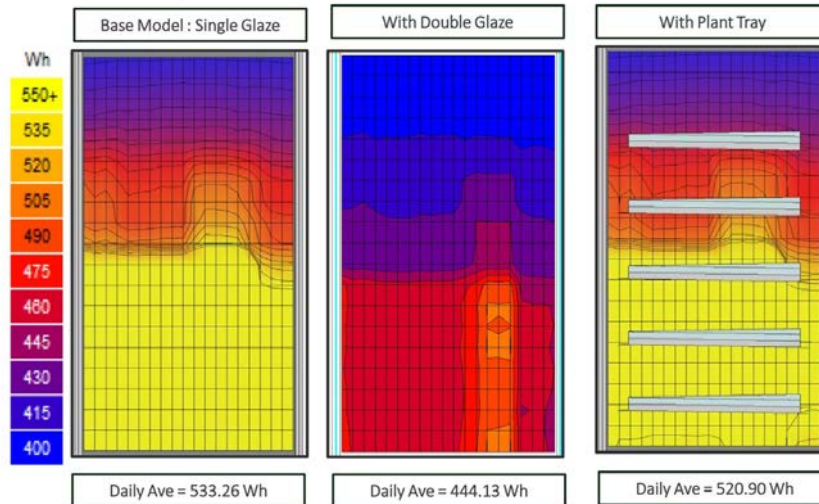
Solar Radiation Analysis



Bio-Facade facing SOUTH - Summer Case

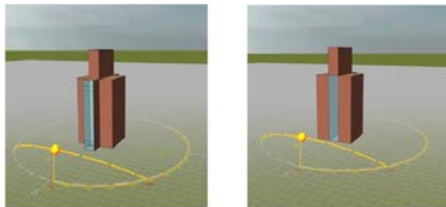
Solar Radiation Analysis

Bio-Facade facing SOUTH - Summer Case



Thermal Analysis

Winter Case (21st Dec) : 18°C set point

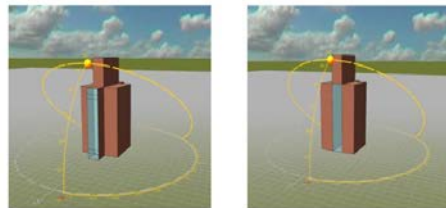


Test to Determine a Simplistic Effect of Bio-Facade on room Heat loss and Heat gain.

A Winter day is modelled to understand how the facade effects room heat loss and heat gain in relation to room heating loads. It is a simplified calculation for an unoccupied room with no internal gains or ventilations

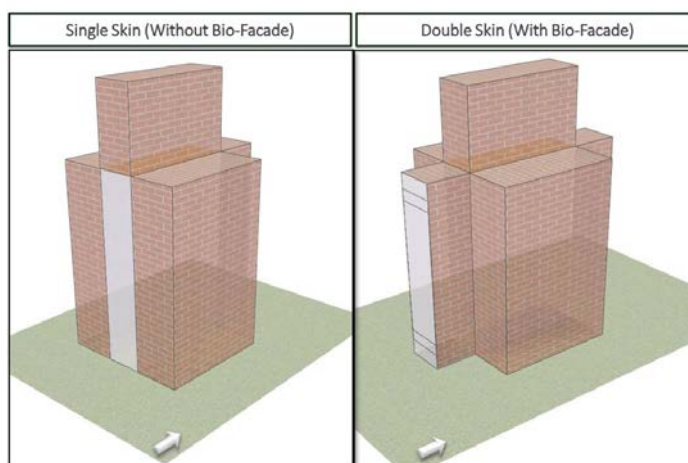
A summer day is modelled to understand the facade as a climate control device.

Summer Case (21st June) : 24°C set point



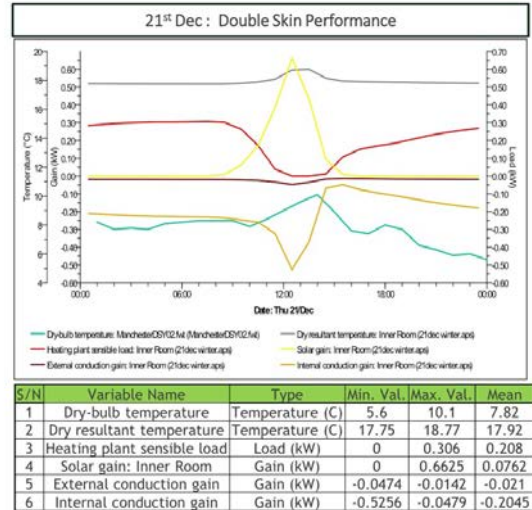
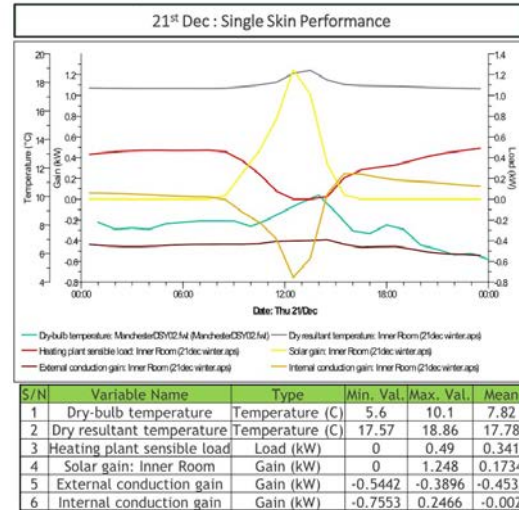
A simplified situation is again modelled looking at the effect of facade in reducing solar gains and room cooling loads. Effect to due the plants (such as humidity and shading) will be modelled at the next stage

Thermal Analysis



Thermal Analysis

Winter Case

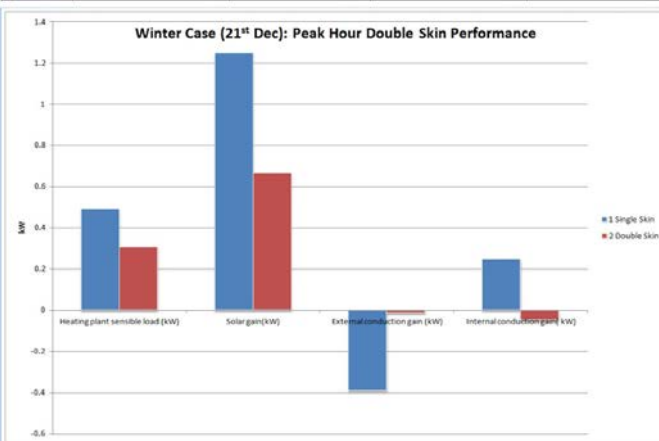


Thermal Analysis

Winter Case

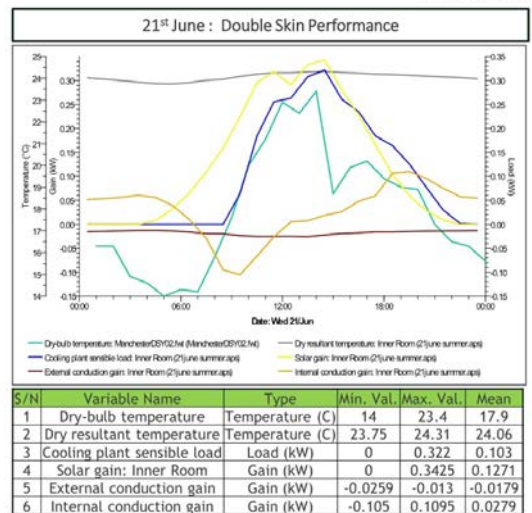
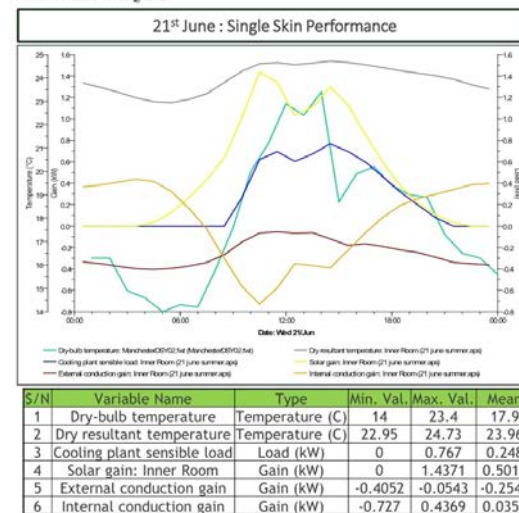
21st Dec : Single Skin Vs Double Skin Performance (Peak value only)

	Heating plant sensible load (kW)	Solar gain(kW)	External conduction gain (kW)	Internal conduction gain (kW)
1 Single Skin	0.49	1.248	-0.3896	0.2466
2 Double Skin	0.306	0.6625	-0.0142	-0.0479



Thermal Analysis

Summer Case

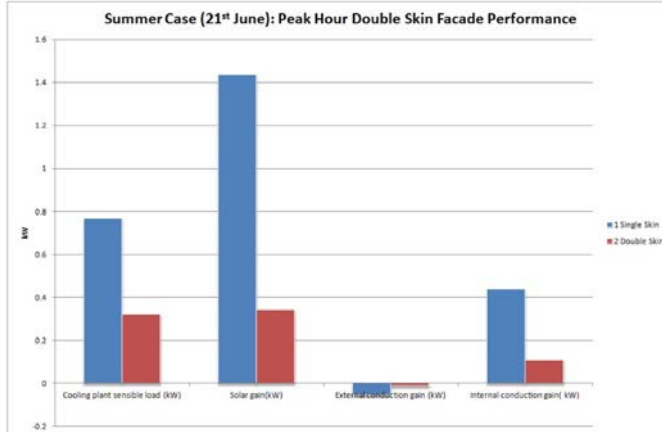


Thermal Analysis

Summer Case

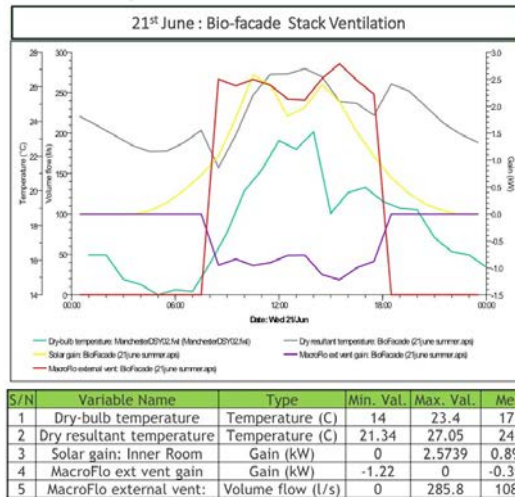
21st June: Single Skin Vs Double Skin Performance (Peak value only)

	Cooling plant sensible load (kW)	Solar gain(kW)	External conduction gain (kW)	Internal conduction gain(kW)
1 Single Skin	0.767	1.4371	-0.0543	0.4368
2 Double Skin	0.322	0.3425	-0.013	0.1095



Thermal Analysis

Summer Case



APPENDIX

R

APPENDIX R

Light analysis - Manchester shadow studies



YIELD ASSESSMENT OF THE PHOTOVOLTAIC POWER PLANT

Report number: PV-5199-1403-2
Issued: 28 March 2014 17:31 (UTC)

1. Site info

Site name: Manchester, United Kingdom

Coordinates: **53° 28' 45.22" N, 02° 14' 52.62" W**
Elevation a.s.l.: 48 m
Slope inclination: 3°
Slope azimuth: 258° west

Annual global in-plane irradiation: **891 kWh/m²**
Annual air temperature at 2 m: **9.2 °C**

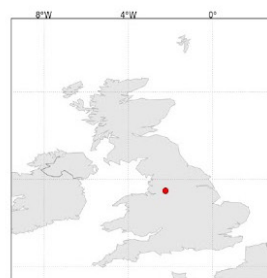
2. PV system info

Installed power: **1.0 kWp**
Type of modules: **crystalline silicon (c-Si)**
Mounting system: **fixed mounting, free standing**
Azimuth/inclination: **180° (south) / 0°**
Inverter Euro eff.: 97.5%
DC / AC losses: 5.5% / 1.5%
Availability: 99.0%

Annual average electricity production: **713 kWh**
Average performance ratio: **80.1%**

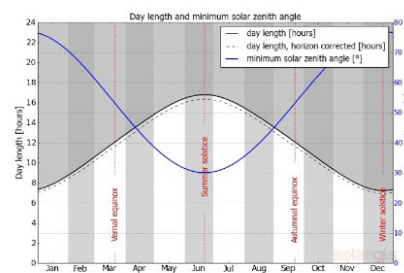
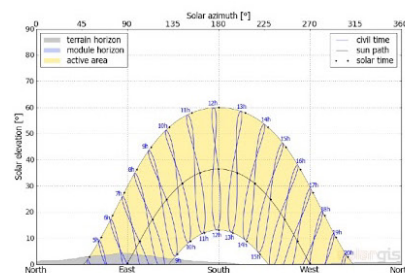
Location on the map: <http://solargis.info/imaps/#loc=53.4792289298,-2.24794864655&tl=Google:Satellite&z=18>

3. Geographic position



Google Maps © 2014 Google

4. Terrain horizon and day length



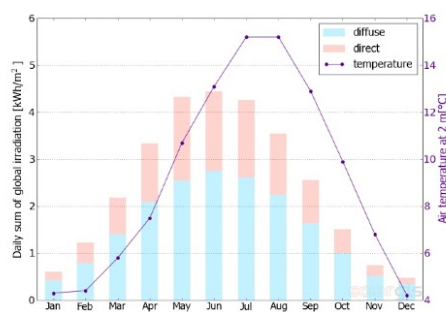
Left: Path of the Sun over a year. Terrain horizon (drawn by grey filling) and module horizon (blue filling) may have shading effect on solar radiation. Black dots show True Solar Time. Blue labels show Local Clock Time.

Right: Change of the day length and solar zenith angle during a year. The local day length (time when the Sun is above the horizon) is shorter compared to the astronomical day length, if obstructed by higher terrain horizon.

Site: Manchester, United Kingdom, lat/lon: 53.4792°/-2.2479°
PV system: 1.0 kWp, crystalline silicon, fixed free, azim. 180° (south), inclination 0°

5. Global horizontal irradiation and air temperature - climate reference

Month	Gh _m	Gh _d	Dh _d	T ₂₄
Jan	19	0.60	0.42	4.3
Feb	34	1.22	0.79	4.4
Mar	68	2.18	1.40	5.8
Apr	100	3.33	2.09	7.5
May	134	4.32	2.54	10.7
Jun	133	4.44	2.74	13.1
Jul	132	4.26	2.61	15.2
Aug	110	3.54	2.24	15.2
Sep	77	2.56	1.63	12.9
Oct	47	1.51	1.00	9.9
Nov	22	0.74	0.51	6.8
Dec	15	0.48	0.34	4.2
Year	891	2.44	1.53	9.2



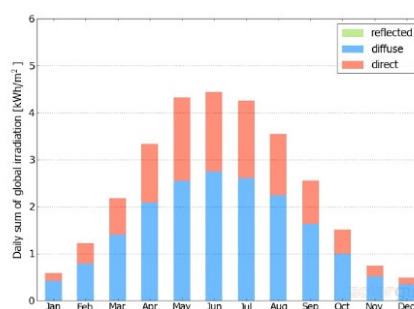
Long-term monthly averages:

Gh_m Monthly sum of global irradiation [kWh/m²]
Gh_d Daily sum of global irradiation [kWh/m²]
Dh_d Daily sum of diffuse irradiation [kWh/m²]
T₂₄ Daily (diurnal) air temperature [°C]

6. Global in-plane irradiation

Fixed surface, azimuth 180° (south), inclination. 0°

Month	Gi _m	Gi _d	Di _d	Ri _d	Sh _{loss}
Jan	19	0.59	0.42	0.00	0.0
Feb	34	1.22	0.79	0.00	0.0
Mar	68	2.18	1.40	0.00	0.0
Apr	100	3.33	2.09	0.00	0.0
May	134	4.32	2.54	0.00	0.0
Jun	133	4.44	2.74	0.00	0.0
Jul	132	4.26	2.61	0.00	0.0
Aug	110	3.54	2.24	0.00	0.0
Sep	77	2.56	1.63	0.00	0.0
Oct	47	1.51	1.00	0.00	0.0
Nov	22	0.74	0.51	0.00	0.0
Dec	15	0.49	0.34	0.00	0.0
Year	891	2.44	1.53	0.00	0.0



Long-term monthly averages:

Gi_m Monthly sum of global irradiation [kWh/m²]
Gi_d Daily sum of global irradiation [kWh/m²]
Di_d Daily sum of diffuse irradiation [kWh/m²]
Ri_d Daily sum of reflected irradiation [kWh/m²]

Sh_{loss} Losses of global irradiation by terrain shading [%]

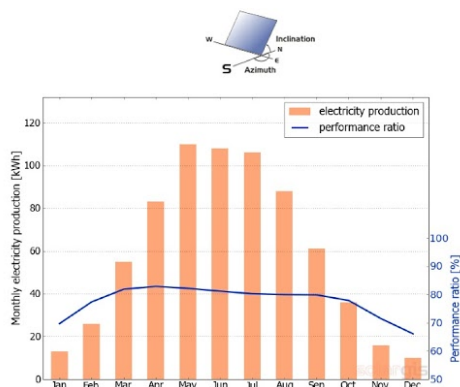
Average yearly sum of global irradiation for different types of surface:

	kWh/m²	relative to optimally inclined
Horizontal	890	86.4%
Optimally inclined (37°)	1029	100.0%
2-axis tracking	1282	124.5%
Your option	890	86.4%

Site: Manchester, United Kingdom, lat/lon: 53.4792°/-2.2479°
PV system: 1.0 kWp, crystalline silicon, fixed free, azim. 180° (south), inclination 0°

7. PV electricity production in the start-up

Month	$E_{s,m}$	$E_{s,d}$	$E_{t,m}$	E_{share}	PR
Jan	12	0.42	13	1.8	69.7
Feb	26	0.94	26	3.7	77.4
Mar	55	1.79	55	7.8	81.9
Apr	82	2.76	83	11.6	82.9
May	110	3.55	110	15.4	82.2
Jun	108	3.61	108	15.2	81.2
Jul	106	3.42	106	14.9	80.3
Aug	87	2.83	88	12.3	80.0
Sep	61	2.04	61	8.6	79.9
Oct	36	1.18	36	5.1	77.9
Nov	15	0.53	16	2.2	71.5
Dec	9	0.32	10	1.4	66.1
Year	712	1.95	713	100.0	80.1



Long-term monthly averages:

$E_{s,m}$ Monthly sum of specific electricity prod. [kWh/kWp]
 $E_{s,d}$ Daily sum of specific electricity prod. [kWh/kWp]
 $E_{t,m}$ Monthly sum of total electricity prod. [kWh]

E_{share} Percentual share of monthly electricity prod. [%]
 PR Performance ratio [%]

8. System losses and performance ratio

Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	890	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	890	0	0.0	100.0	100.0
3. Global irradiation reduced by reflectivity	845	-45	-5.1	94.9	94.9
4. Conversion to DC in the modules	794	-51	-6.0	94.0	89.2
5. Other DC losses	750	-44	-5.5	94.5	84.3
6. Inverters (DC/AC conversion)	731	-19	-2.5	97.5	82.1
7. Transformer and AC cabling losses	720	-11	-1.5	98.5	80.9
8. Reduced availability	713	-7	-1.0	99.0	80.1
Total system performance	713	-177	-19.9	-	80.1

Energy conversion steps and losses:

1. Initial production at Standard Test Conditions (STC) is assumed,
2. Reduction of global in-plane irradiation due to obstruction of terrain horizon and PV modules,
3. Proportion of global irradiation that is reflected by surface of PV modules (typically glass),
4. Losses in PV modules due to conversion of solar radiation to DC electricity; deviation of module efficiency from STC,
5. DC losses: this step assumes integrated effect of mismatch between PV modules, heat losses in interconnections and cables, losses due to dirt, snow, icing and soiling, and self-shading of PV modules,
6. This step considers euro efficiency to approximate average losses in the inverter,
7. Losses in AC section and transformer (where applicable) depend on the system architecture,
8. Availability parameter assumes losses due to downtime caused by maintenance or failures.

Losses at steps 2 to 4 are numerically modeled by pvPlanner. Losses at steps 5 to 8 are to be assessed by a user. The simulation models have inherent uncertainties that are not discussed in this report. Read more about simulation methods and related uncertainties to evaluate possible risks at <http://solargis.info/doc/pvplanner/>.



Rooftop / December 21st - 9:00 - 15:00



Rooftop / January and November 21st - 9:00 - 15:30



Rooftop / February and October 21st - 8:00 - 16:30



Rooftop / March and September 21st - 7:00 - 17:30



Rooftop / April and August 21st - 7:00 - 19:00



Rooftop / May and July 21st - 6:00 - 20:00



Rooftop / June 21st - 5:30 - 20:30



Facade South West / December 21st - 9:00 - 15:00



Facade South East / December 21st - 9:00 - 15:00



Facade South West / March and September 21st - 7:00 - 17:30



Facade South East / March and September 21st - 7:00 - 17:30



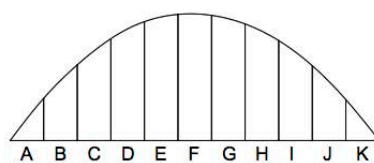
Facade South West / June 21st - 5:30 - 20:30



Facade South East / June 21st - 5:30 - 20:30

December 21st		Monthly light capture		Annual light capture	
Time	Section	Impact %	Opacity	Impact %	Opacity
09:30	A	2.3	12	0	0
10:00	B	6.4	32	0.1	1
10:30	C	9.6	48	0.1	1
11:00	D	12	60	0.2	2
11:30	E	13.3	66	0.2	2
12:00	F	13.6	68	0.2	2
12:30	G	13.3	66	0.2	2
13:00	H	12	60	0.2	2
13:30	I	9.6	48	0.1	1
14:00	J	6.4	32	0.1	1
14:30	K	2.3	12	0	0

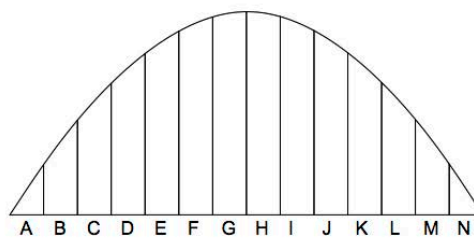
December 21st light capture data



December sun curve

Jan./Nov. 21st		Monthly light capture		Annual light capture	
Time	Section	Impact %	Opacity	Impact %	Opacity
09:00	A	1.4	7	0	1
09:30	B	3.9	20	0.1	2
10:00	C	6.1	31	0.2	4
10:30	D	7.9	40	0.2	5
11:00	E	9.3	47	0.3	6
11:30	F	10.3	52	0.3	6
12:00	G	10.9	54	0.3	6
12:30	H	10.9	54	0.3	6
13:00	I	10.3	52	0.3	6
13:30	J	9.3	47	0.3	6
14:00	K	7.9	40	0.2	5
14:30	L	6.1	31	0.2	4
15:00	M	3.9	20	0.1	2
15:30	N	1.4	7	0	1

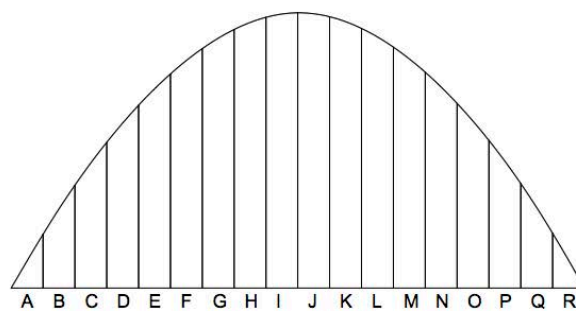
January 21st / November 21st light capture data



January / November sun curve

Feb./Oct. 21st		Monthly light capture		Annual light capture	
Time	Section	Impact %	Opacity	Impact %	Opacity
08:00	A	0.8	4	0	1
08:30	B	2.4	12	0.1	2
09:00	C	3.9	19	0.2	4
09:30	D	5.1	25	0.3	5
10:00	E	6.2	31	0.3	6
10:30	F	7	35	0.4	7
11:00	G	7.7	39	0.4	8
11:30	H	8.2	41	0.4	8
12:00	I	8.5	42	0.4	8
12:30	J	8.5	42	0.4	8
13:00	K	8.2	41	0.4	8
13:30	L	7.7	39	0.4	8
14:00	M	7	35	0.4	7
14:30	N	6.2	31	0.3	6
15:00	O	5.1	25	0.3	5
15:30	P	3.9	19	0.2	4
16:00	Q	2.4	12	0.1	2
16:30	R	0.8	4	0	1

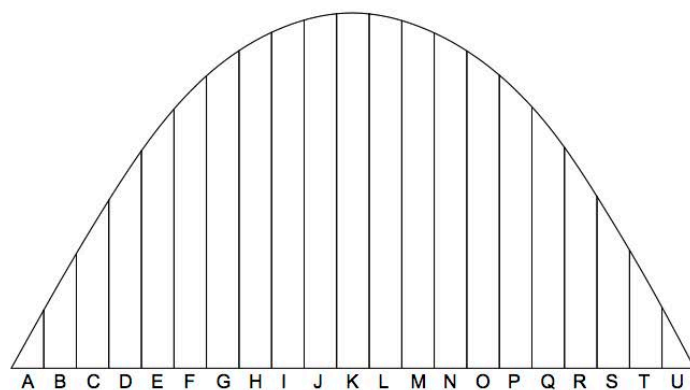
February 21st / October 21st light capture data



February / October sun curve

March/Sept. 21st		Monthly light capture		Annual light capture	
Time	Section	Impact %	Opacity	Impact %	Opacity
07:30	A	0.6	3	0	1
08:00	B	1.7	9	0.1	3
08:30	C	2.9	14	0.2	4
09:00	D	3.9	19	0.3	6
09:30	E	4.8	24	0.4	7
10:00	F	5.6	28	0.4	8
10:30	G	6.2	31	0.5	9
11:00	H	6.6	33	0.5	10
11:30	I	6.9	35	0.5	11
12:00	J	7.1	35	0.5	11
12:30	K	7.2	36	0.5	11
13:00	L	7.1	35	0.5	11
13:30	M	6.9	35	0.5	11
14:00	N	6.6	33	0.5	10
14:30	O	6.2	31	0.5	9
15:00	P	5.6	28	0.4	8
15:30	Q	4.8	24	0.4	7
16:00	R	3.9	19	0.3	6
16:30	S	2.9	14	0.2	4
17:00	T	1.7	9	0.1	3
17:30	U	0.6	3	0	1

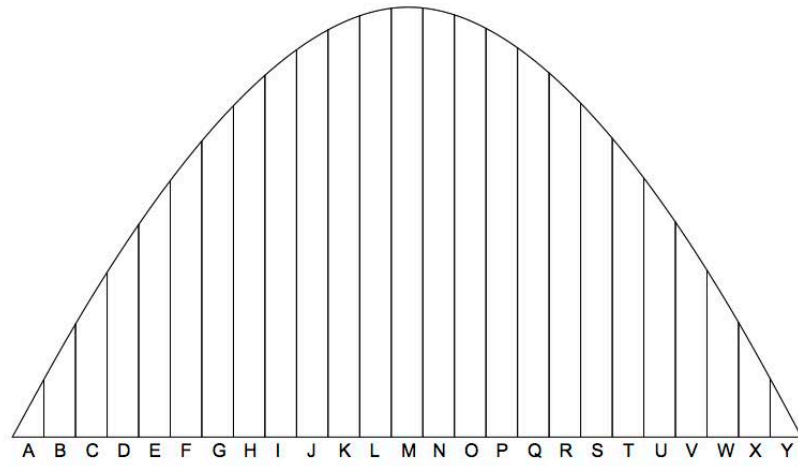
March 21st / September 21st light capture data



March / September sun curve

April/Aug. 21st		Monthly light capture		Annual light capture	
Time	Section	Impact %	Opacity	Impact %	Opacity
07:00	A	0.4	2	0	1
07:30	B	1.2	6	0.1	3
08:00	C	2	10	0.2	4
08:30	D	2.7	14	0.3	6
09:00	E	3.4	17	0.4	7
09:30	F	4	20	0.4	8
10:00	G	4.5	23	0.5	9
10:30	H	5	25	0.5	10
11:00	I	5.4	27	0.6	11
11:30	J	5.8	29	0.6	12
12:00	K	6	30	0.6	12
12:30	L	6.2	31	0.6	13
13:00	M	6.2	31	0.6	13
13:30	N	6.2	31	0.6	13
14:00	O	6	30	0.6	12
14:30	P	5.8	29	0.6	12
15:00	Q	5.4	27	0.6	11
15:30	R	5	25	0.5	10
16:00	S	4.5	23	0.5	9
16:30	T	4	20	0.4	8
17:00	U	3.4	17	0.4	7
17:30	V	2.7	14	0.3	6
18:00	W	2	10	0.2	4
18:30	X	1.2	6	0.1	3
19:00	Y	0.4	2	0	1

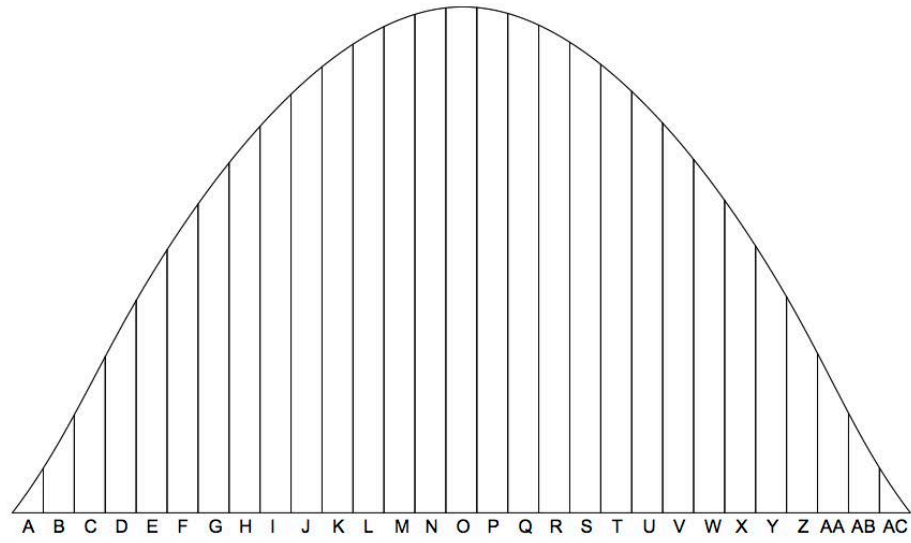
April 21st / August 21st light capture data



April / August sun curve

May/July 21st		Monthly light capture		Annual light capture	
Time	Section	Impact %	Opacity	Impact %	Opacity
06:00	A	0.2	1	0	1
06:30	B	0.8	4	0.1	2
07:00	C	1.4	7	0.2	4
07:30	D	2	10	0.3	5
08:00	E	2.6	13	0.3	7
08:30	F	3.1	15	0.4	8
09:00	G	3.5	18	0.5	10
09:30	H	4	20	0.5	11
10:00	I	4.3	22	0.6	12
10:30	J	4.6	23	0.6	13
11:00	K	4.9	25	0.7	13
11:30	L	5.1	26	0.7	14
12:00	M	5.3	26	0.7	14
12:30	N	5.4	27	0.7	15
13:00	O	5.4	27	0.7	15
13:30	P	5.4	27	0.7	15
14:00	Q	5.3	26	0.7	14
14:30	R	5.1	26	0.7	14
15:00	S	4.9	25	0.7	13
15:30	T	4.6	23	0.6	13
16:00	U	4.3	22	0.6	12
16:30	V	4	20	0.5	11
17:00	W	3.5	18	0.5	10
17:30	X	3.1	15	0.4	8
18:00	Y	2.6	13	0.3	7
18:30	Z	2	10	0.3	5
19:00	AA	1.4	7	0.2	4
19:30	AB	0.8	4	0.1	2
20:00	AC	0.2	1	0	1

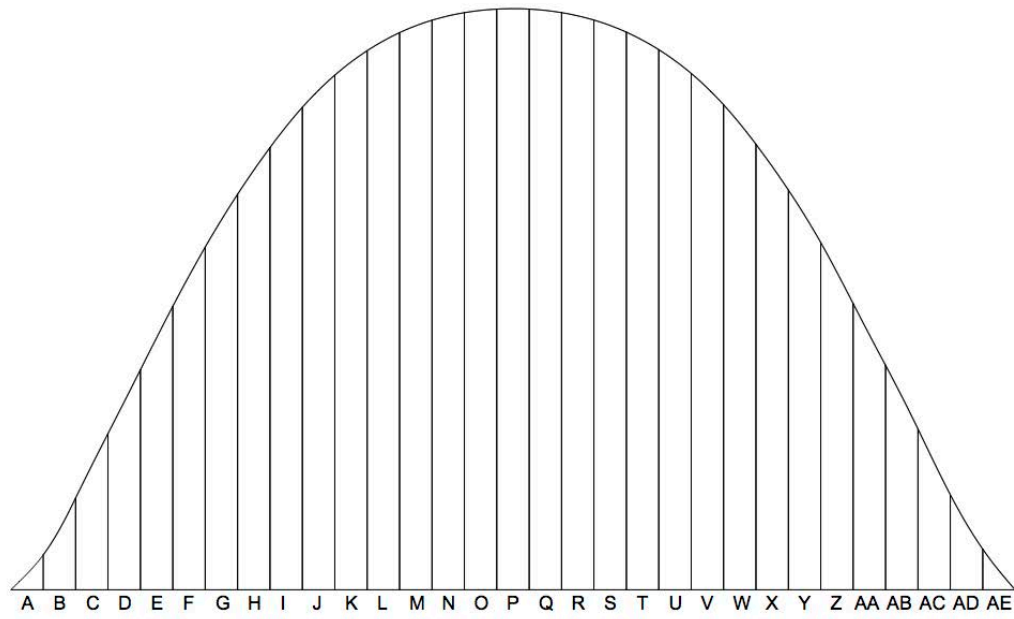
May 21st / July 21st light capture data



May / July sun curve

June 21st		Monthly light capture		Annual light capture	
Time	Section	Impact %	Opacity	Impact %	Opacity
05:30	A	0.2	1	0	0
06:00	B	0.5	3	0.1	1
06:30	C	1.1	5	0.2	2
07:00	D	1.6	8	0.3	3
07:30	E	2.2	11	0.4	4
08:00	F	2.7	13	0.5	5
08:30	G	3.2	16	0.6	6
09:00	H	3.6	18	0.6	6
09:30	I	4	20	0.7	7
10:00	J	4.3	21	0.8	8
10:30	K	4.5	23	0.8	8
11:00	L	4.7	24	0.8	8
11:30	M	4.9	24	0.9	9
12:00	N	4.9	25	0.9	9
12:30	O	5	25	0.9	9
13:00	P	5	25	0.9	9
13:30	Q	5	25	0.9	9
14:00	R	4.9	25	0.9	9
14:30	S	4.9	24	0.9	9
15:00	T	4.7	24	0.8	8
15:30	U	4.5	23	0.8	8
16:00	V	4.3	21	0.8	8
16:30	W	4	20	0.7	7
17:00	X	3.6	18	0.6	6
17:30	Y	3.2	16	0.6	6
18:00	Z	2.7	13	0.5	5
18:30	AA	2.2	11	0.4	4
19:00	AB	1.6	8	0.3	3
19:30	AC	1.1	5	0.2	2
20:00	AD	0.5	3	0.1	1
20:30	AE	0.2	1	0	0

June 21st light capture data



June sun curve

APPENDIX

S

APPENDIX S

Inner urban area analysis



Aberdeen - 163 Hectares



Armagh - 39 Hectares



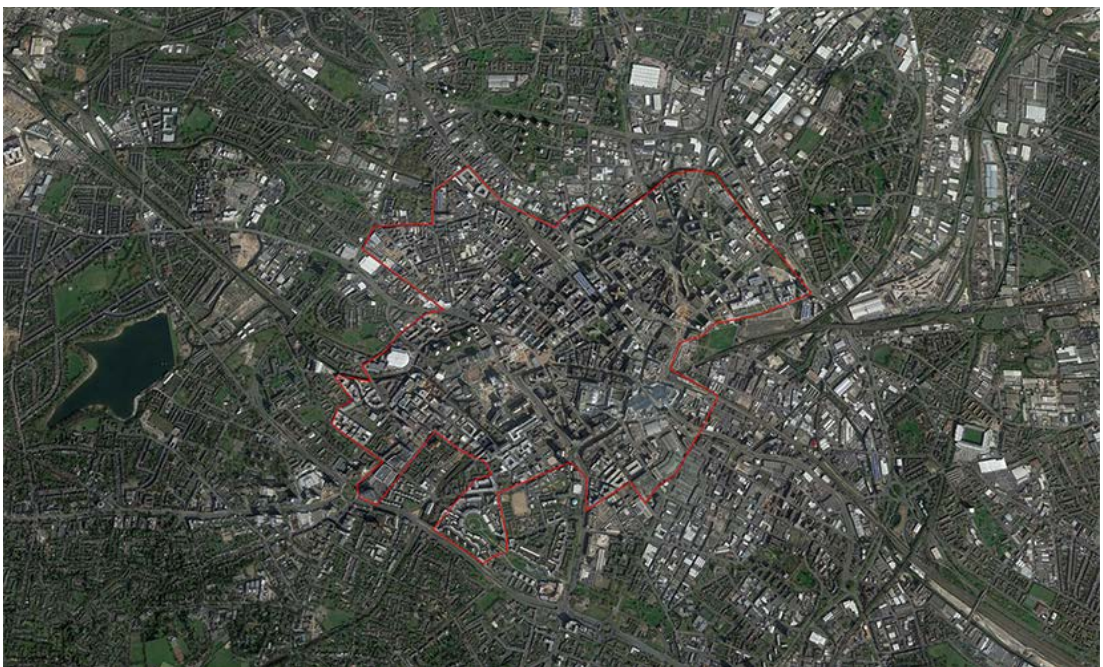
Bangor - 38 Hectares



Bath - 43 Hectares



Belfast - 154 Hectares



Birmingham - 339 Hectares



Bradford - 74 Hectares



Brighton and Hove - 45 Hectares



Bristol - 172 Hectares



Cambridge - 38 Hectares



Canterbury - 28 Hectares



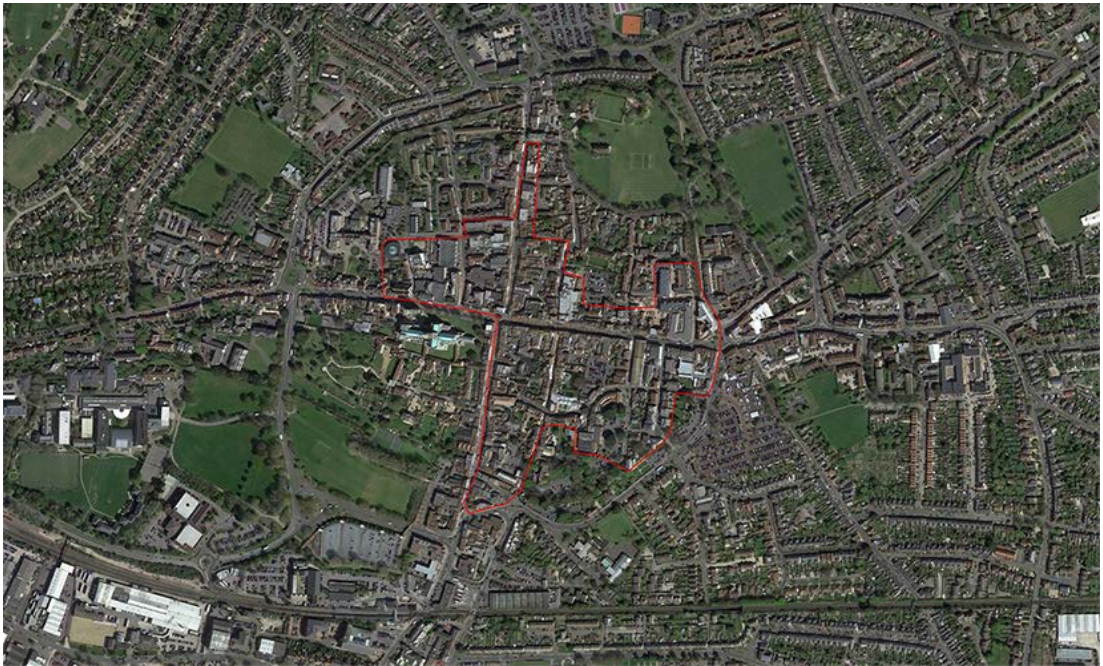
Cardiff - 91 Hectares



Carlisle - 63 Hectares



Chester - 31 Hectares



Chichester - 16 Hectares



City of London and Westminster - 1370 Hectares



Coventry - 90 Hectares



Derby - 48 Hectares



Dundee - 106 Hectares



Durham - 14 Hectares



Edinburgh - 175 Hectares



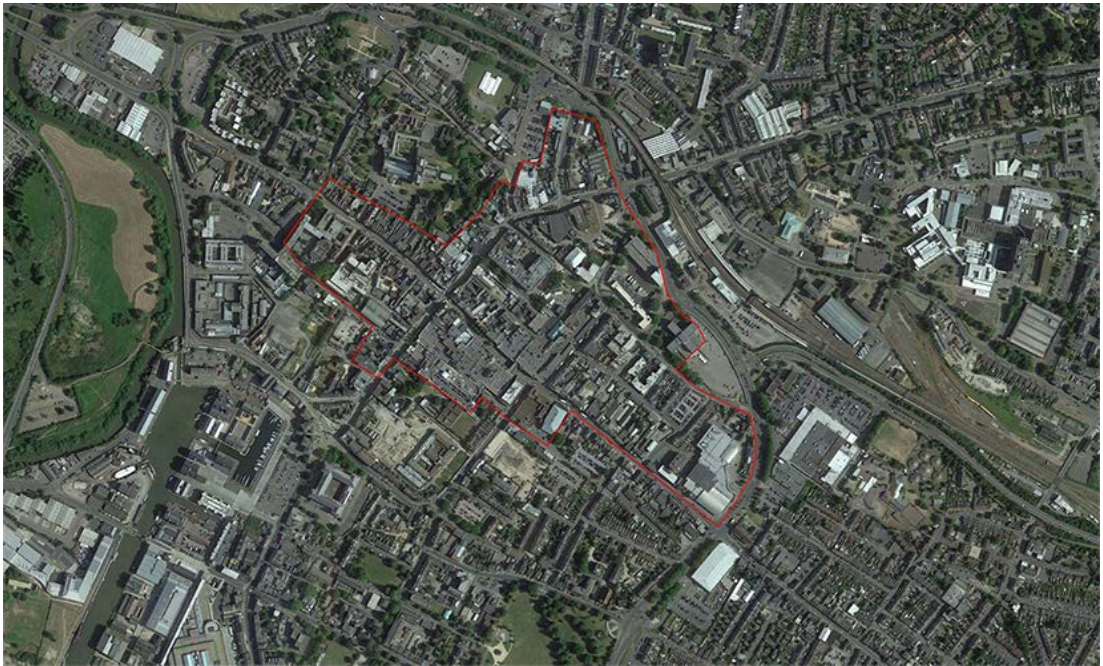
Ely - 9 Hectares



Exeter - 54 Hectares



Glasgow - 183 Hectares



Gloucester - 27 Hectares



Hereford - 23 Hectares



Inverness - 23 Hectares



Kingston upon hull - 73 Hectares



Lancaster - 15 Hectares



Leeds - 118 Hectares



Leicester - 109 Hectares



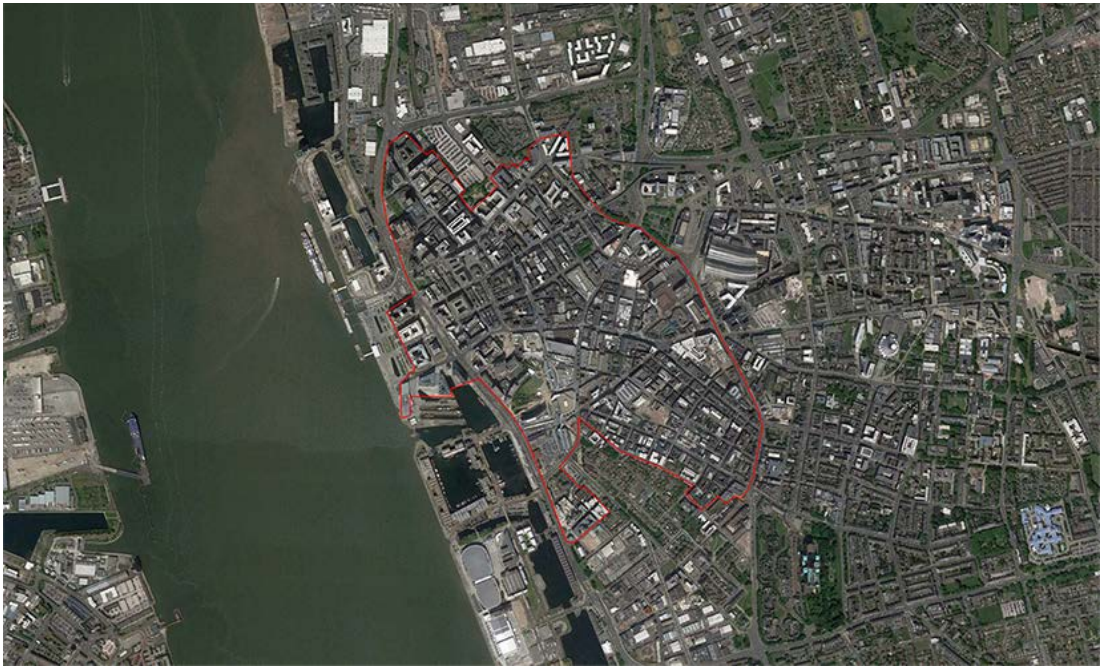
Lichfield - 9 Hectares



Lincoln - 27 Hectares



Lisburn - 12 Hectares



Liverpool - 117 Hectares



Londonderry - 21 Hectares



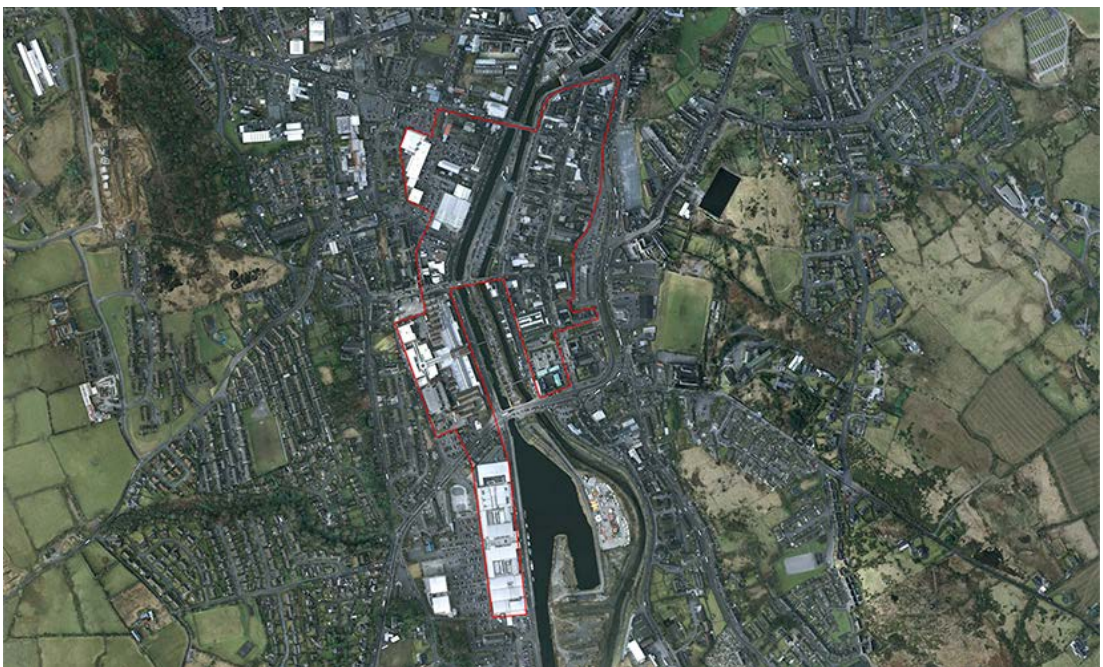
Manchester - 360 Hectares



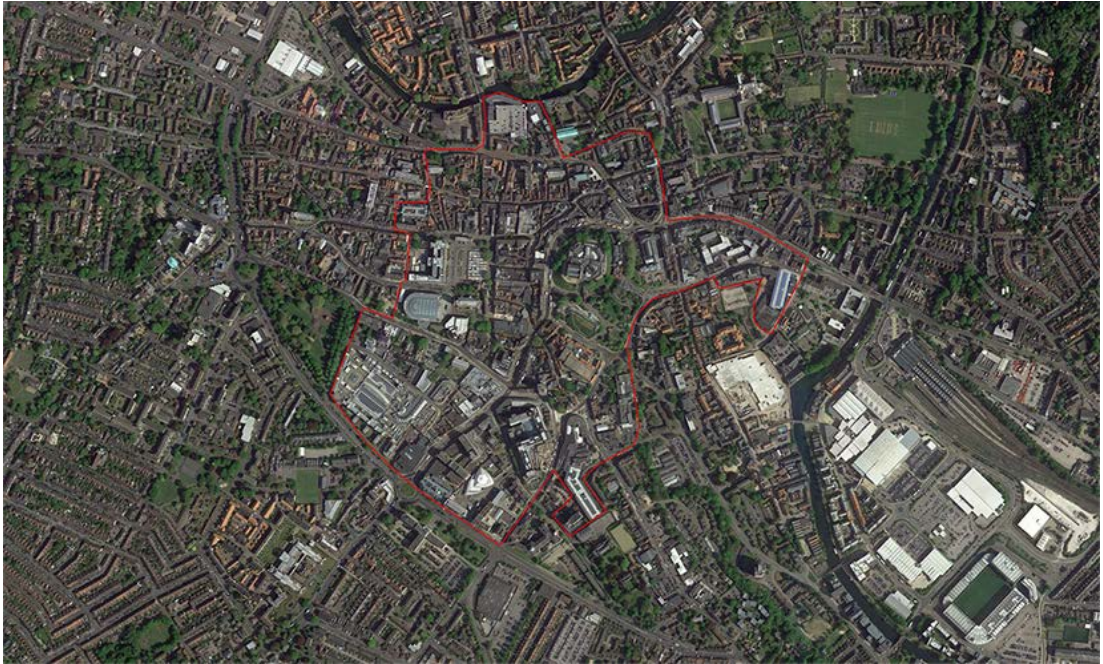
Newcastle upon tyne - 153 Hectares



Newport - 19 Hectares



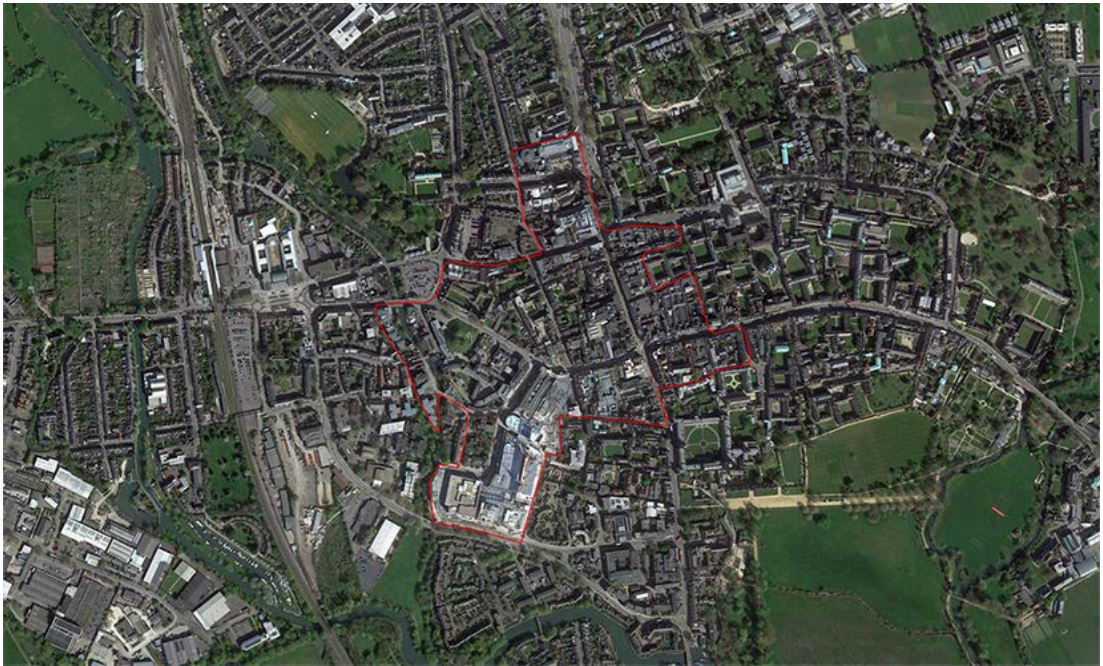
Newry - 23 Hectares



Norwich - 50 Hectares



Nottingham - 88 Hectares



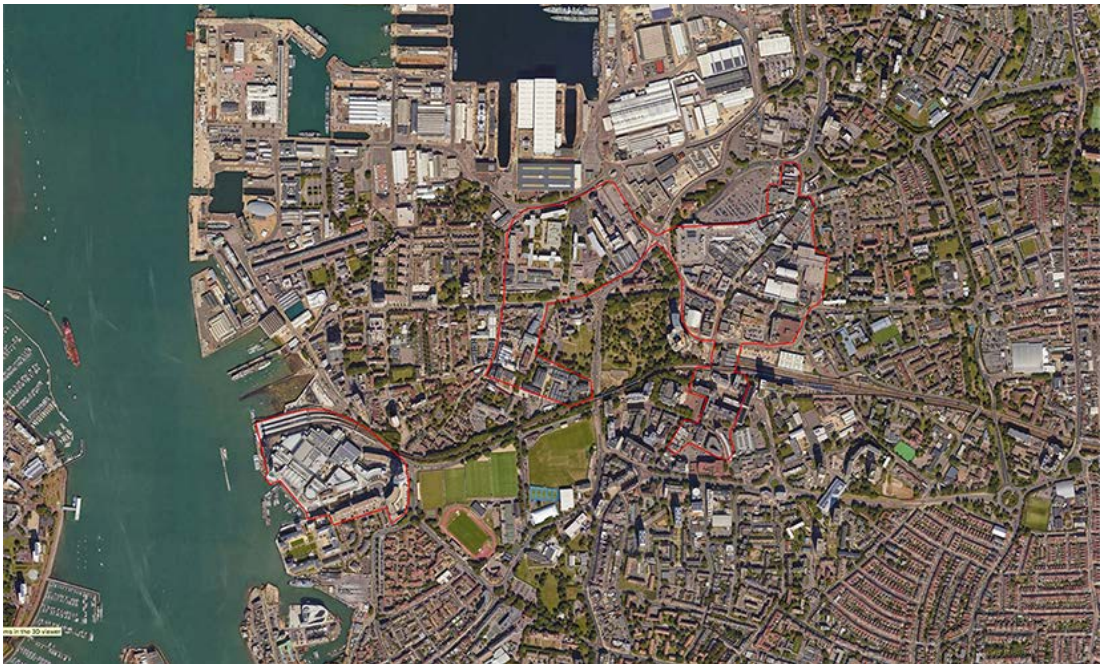
Oxford - 27 Hectares



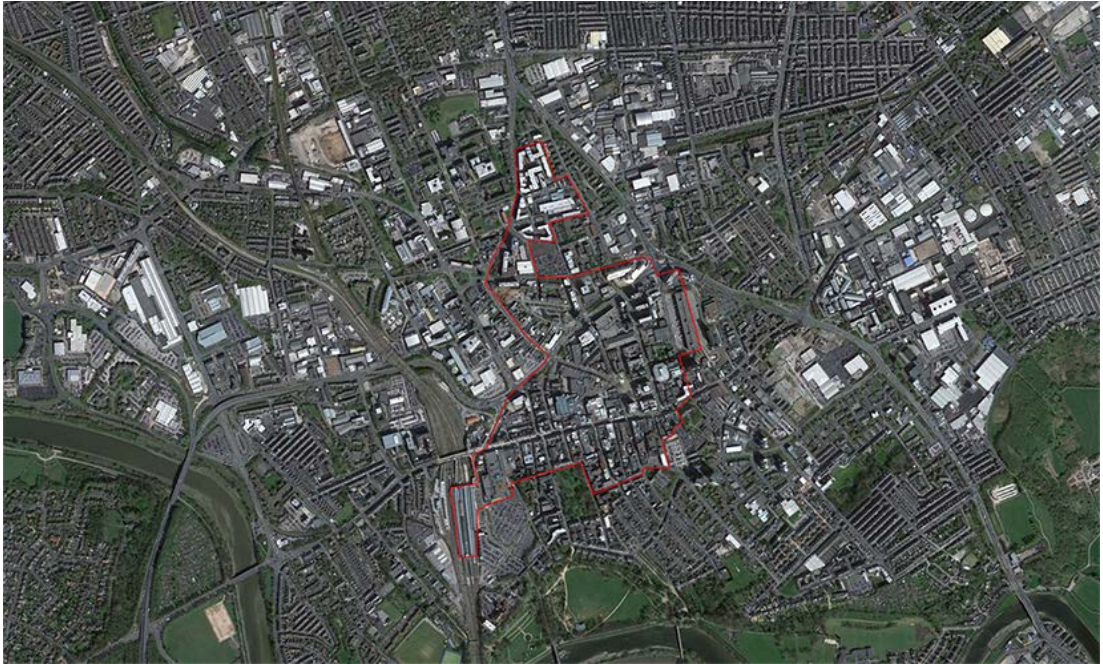
Peterborough - 26 Hectares



Plymouth - 66 Hectares



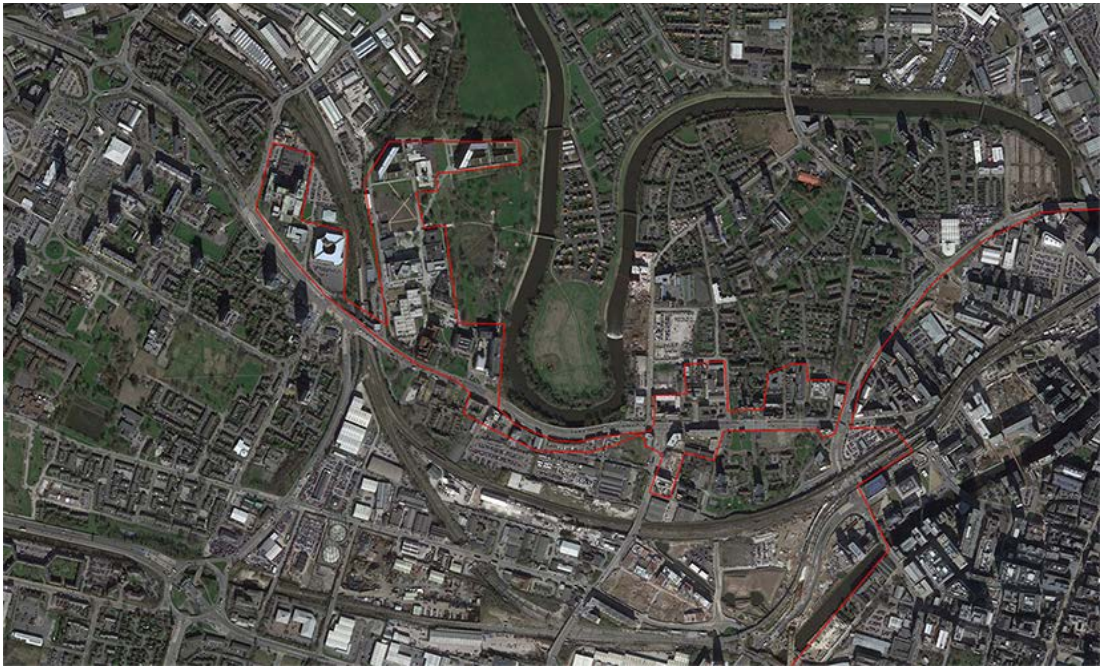
Portsmouth - 41 Hectares



Preston - 47 Hectares



Ripon - 7 Hectares



Salford - 27 Hectares



Salisbury - 10 Hectares



Sheffield - 141 Hectares



Southampton - 53 Hectares



St. Albans - 18 Hectares



St. Davids - 0 Hectares



Stirling - 16 Hectares



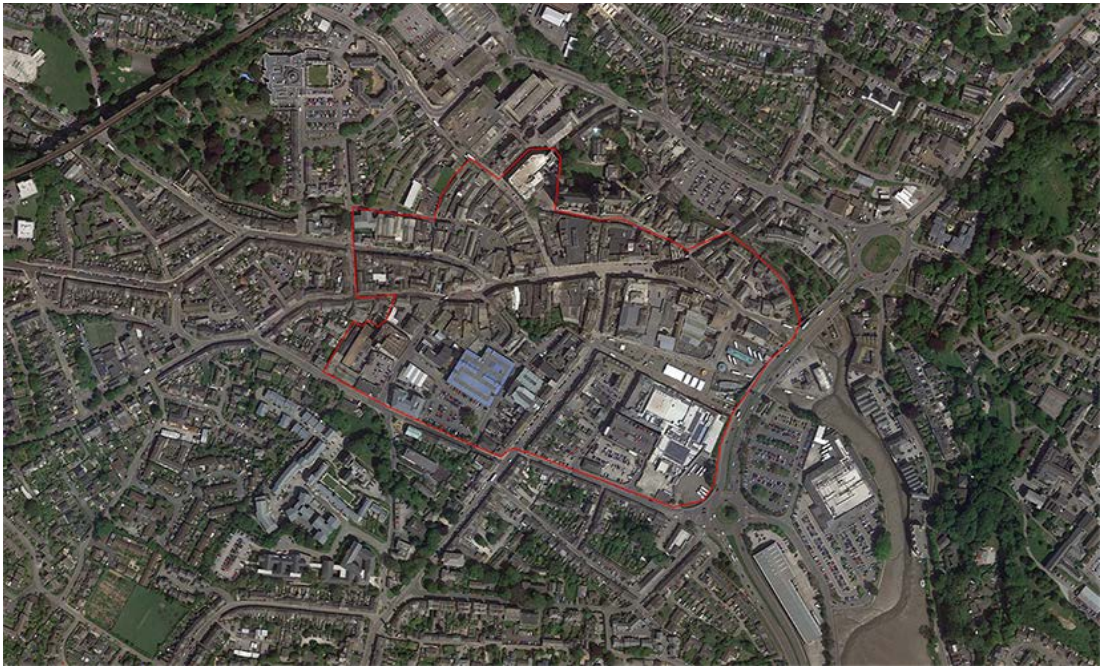
Stoke-on-Trent - 84 Hectares



Sunderland - 56 Hectares



Swansea - 41 Hectares



Truro - 16 Hectares



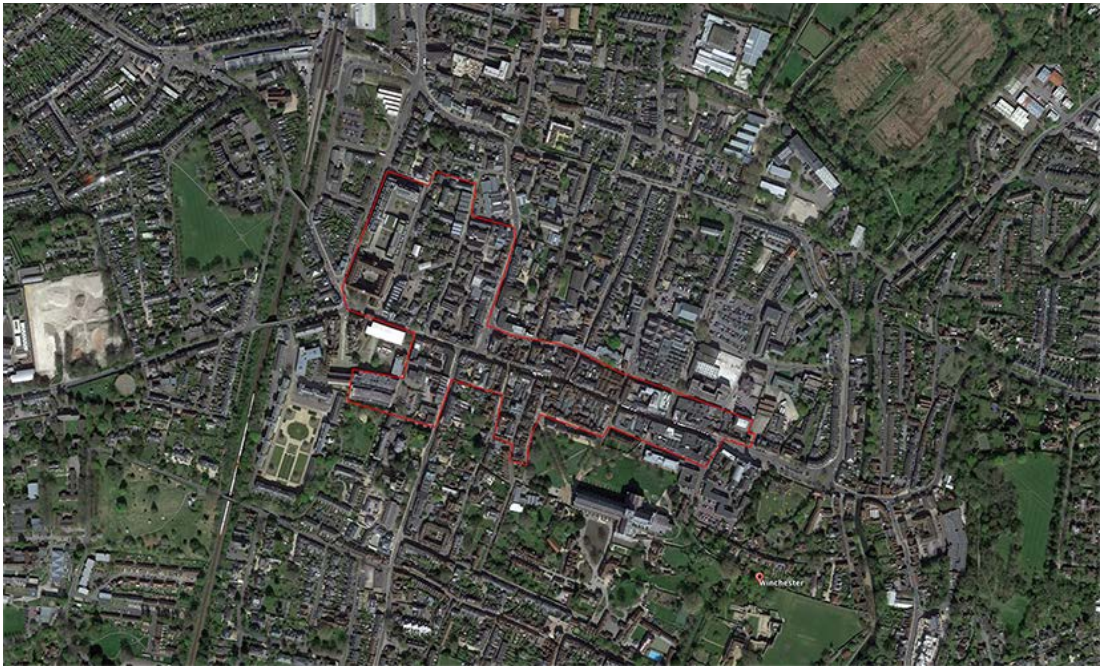
Wakefield - 34 Hectares



Wells - 6 Hectares



Westminster - Included with City of London and Westminster area



Winchester - 12 Hectares



Wolverhampton - 60 Hectares



Worcester - 25 Hectares



York - 23 Hectares

UK total inner urban area = 5,486 hectares